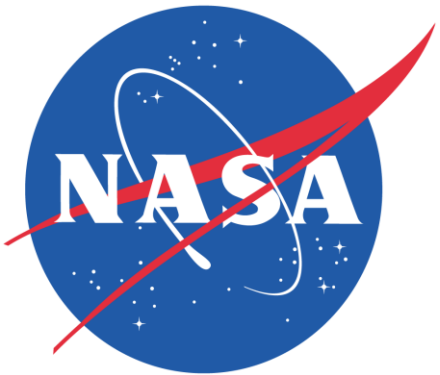
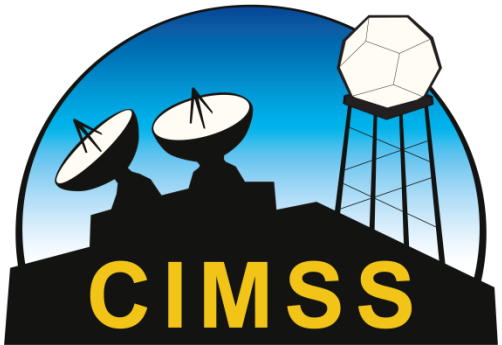
Aura Chemical Reanalysis in support of Air Quality Applications

R. Bradley Pierce (NOAA/NESDIS), Allen Lenzen, Todd Schaack, Marek Rogal, and Andrew Wentland (UW-Madison, CIMSS/AOS)

Data provided by: Ryan Spackman, Owen Cooper, Tom Ryerson, (NOAA/ESRL), Anne Thompson, (PSU/GFSC), Andrew Weinheimer (NCAR), Ed Eloranta, (UW-Madison), Alan Fried (Univ Colorado), and the Aura Science Team





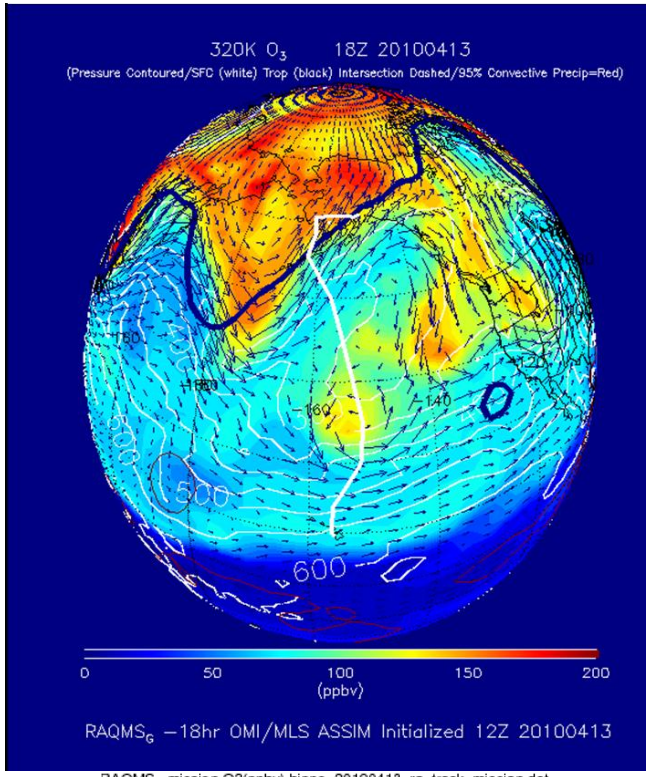
New activity funded by the ROSES-2013 call for an Applied Science representative on the Aura Science Team

- Funded by the Applied Science Program
- Inter-agency purchase request initiated in April 2014
- CIMSS received funding in August, 2014

So…. We're just beginning the project

Focus

- **Provide the air quality community with a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements.**
- Conduct regional chemical data assimilation experiments to quantify the influences in changes in NOx emissions on US air quality during the Aura period.
- Collaborate with International, Federal, State and Local air quality management communities in the utilization of the Aura and A-Train measurements and reanalysis for air quality assessment activities.



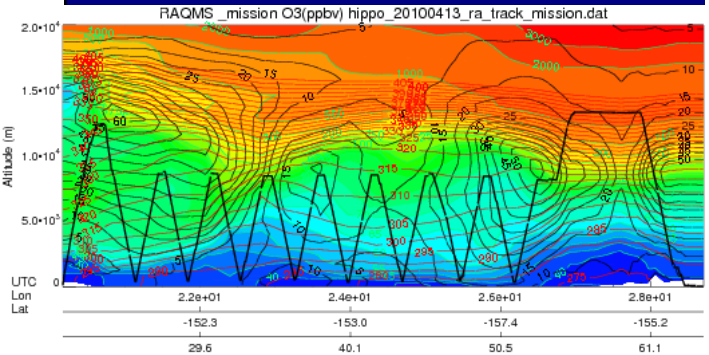
1. **Online global chemical and aerosol assimilation/ forecasting system**

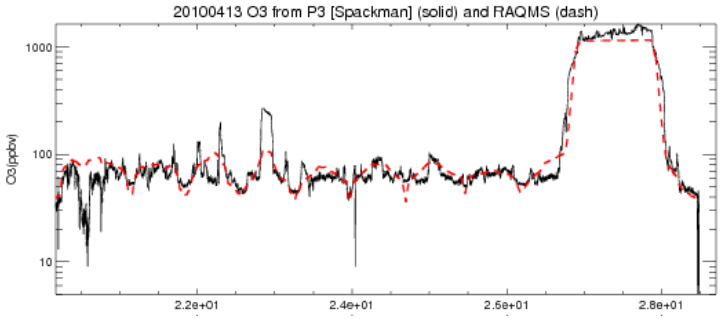
2. **UW-Madison sigma-theta hybrid coordinate model (UW-Hybrid) dynamical core**

3. **Unified stratosphere/troposphere chemical prediction scheme (LaRC-Combo) developed at NASA LaRC**

4. **Aerosol prediction scheme (GOCART) developed by Mian Chin (NASA GSFC).**

5. **Statistical Digital Filter (OI) assimilation system developed by James Stobie (NASA/GFSC)**





HIPPO March-April 2010, Mission scientist: Steve Wofsy (Harvard), O3 PI: Ryan Spackman (NOAA/ESRL)

The RAQMS real-time assimilation/forecast system has been running continuously since January 2012 (N Amer: http://raqms-ops.ssec.wisc.edu/, CONUS: http://raqms.ssec.wisc.edu/)

Aura Chemical Reanalysis assimilation configuration:

NOAA Grid-point Statistical Interpolation (GSI) 3D variational analysis of:

- **Aura Microwave Limb Sounder (MLS)**
  - **O3, H2O, HCL, HNO3, N2O, and CO (?) profiles**
- **Aura Ozone Monitoring Instrument (OMI)**
  - **Total Column (profile ?) O3, NO2, and HCHO (?)**
- **Aura Tropospheric Emission Spectrometer (TES)**
  - **O3, CO, CH4, and N2O**
- **Aqua Atmospheric Infrared Sounder (AIRS)**
  - **O3, CO, CH4, and N2O**

Need to evaluate impact of reduction in TES Global Survey sampling

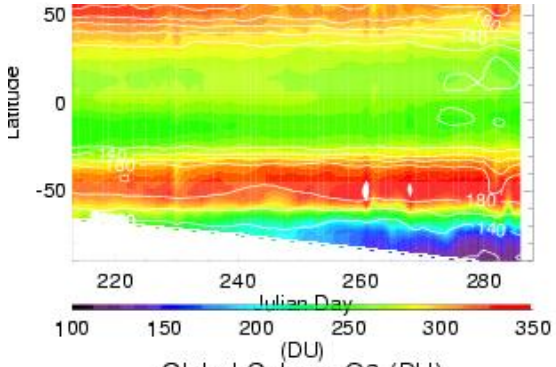
- **Terra/Aqua Moderate Resolution Imaging Spectroradiometer (MODIS)**
  - **Aerosol Optical Depth (AOD), fire detection**

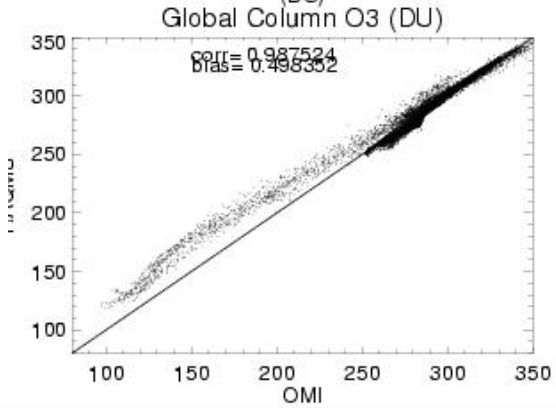
Data Denial Experiments using Aura, Terra, and Aqua retrievals

Field Mission	Partner Air Quality Agency
2006 TEXAQS • OMI O3 • OMI+TES O3	Texas Commission on Environmental Quality
2010 CalNex • OMI+MLS O3	California Air Resources Board
2014 FRAPPE/DISCOVER-AQ • OMI+MLS O3 • MODIS AOD	CDPHE CO Colorado Department of Public Health & Environment

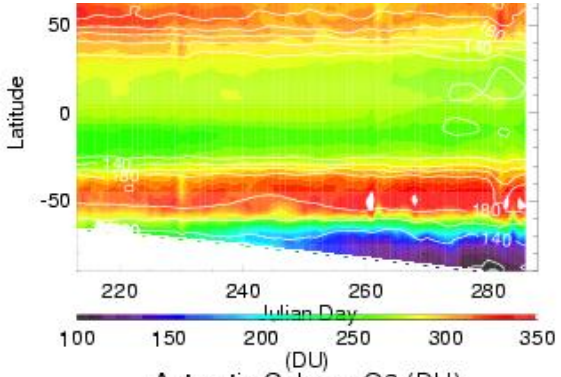
TEXAQS Total Column Ozone Timeseries August 01- October 15, 2006
Assimilation of OMI Total column ozone

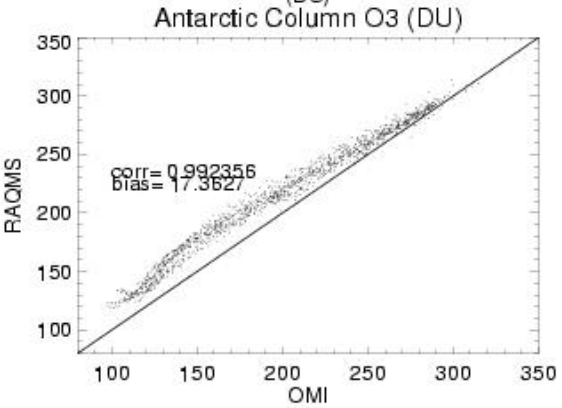
RAQMS Column O3
Analysis
Aug 01- Oct 15, 2006





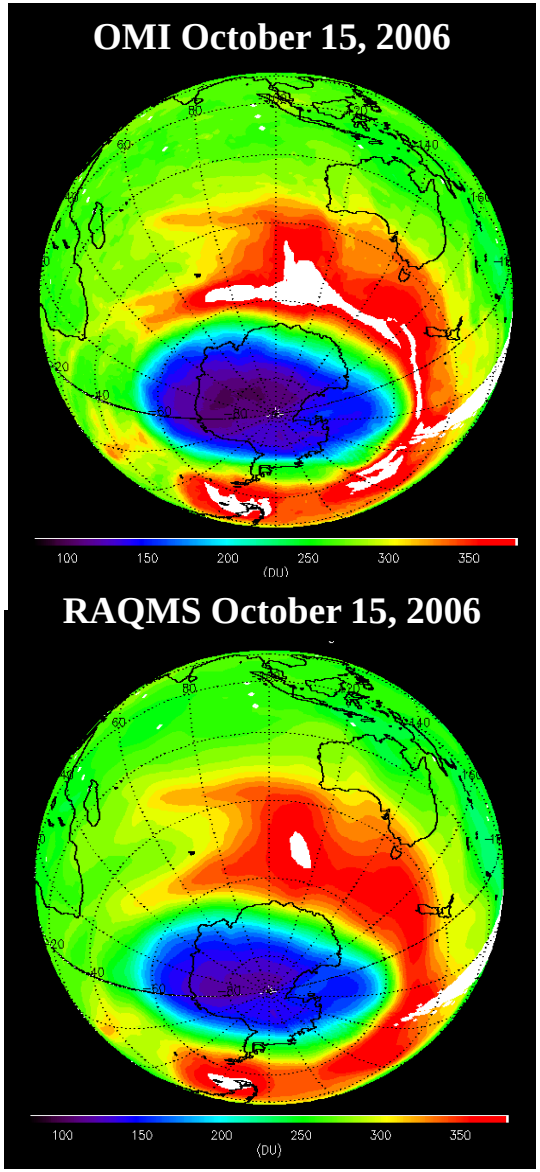
OMI Column O3
Observations
Aug 01- Oct 15, 2006





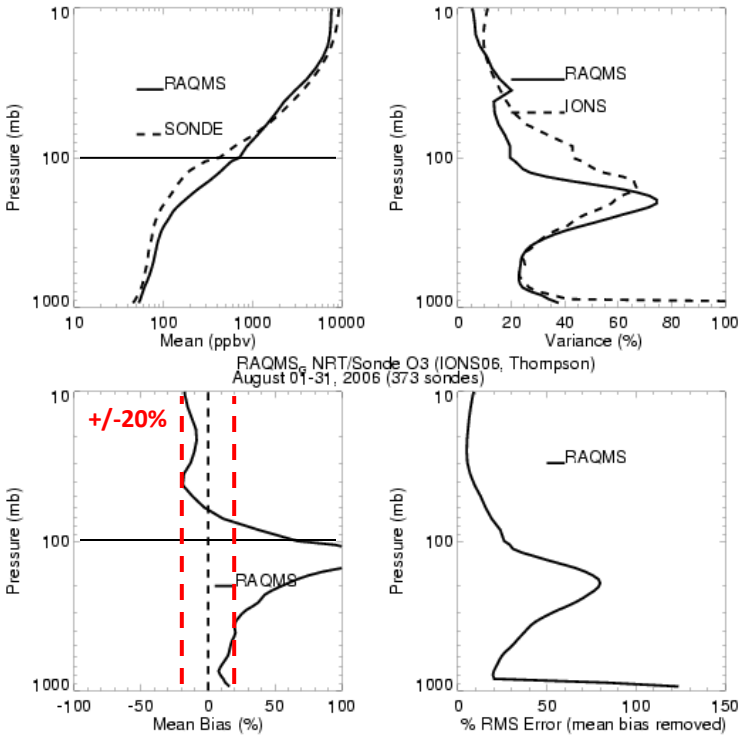
Assimilation of cloud-cleared OMI ozone column captures observed mid-latitude temporal and latitudinal variations.

RAQMS analysis underestimates mid-September through mid-October (Julian day 260-290) Antarctic ozone loss by 17%.



Record breaking ozone loss during October, 2006

Comparison of RAQMS NRT OMI analysis with ozonesondes during TEXAQS (373 sondes, August, 2006)



Assimilation of OMI total column ozone results in large high bias in upper troposphere/ lower stratosphere

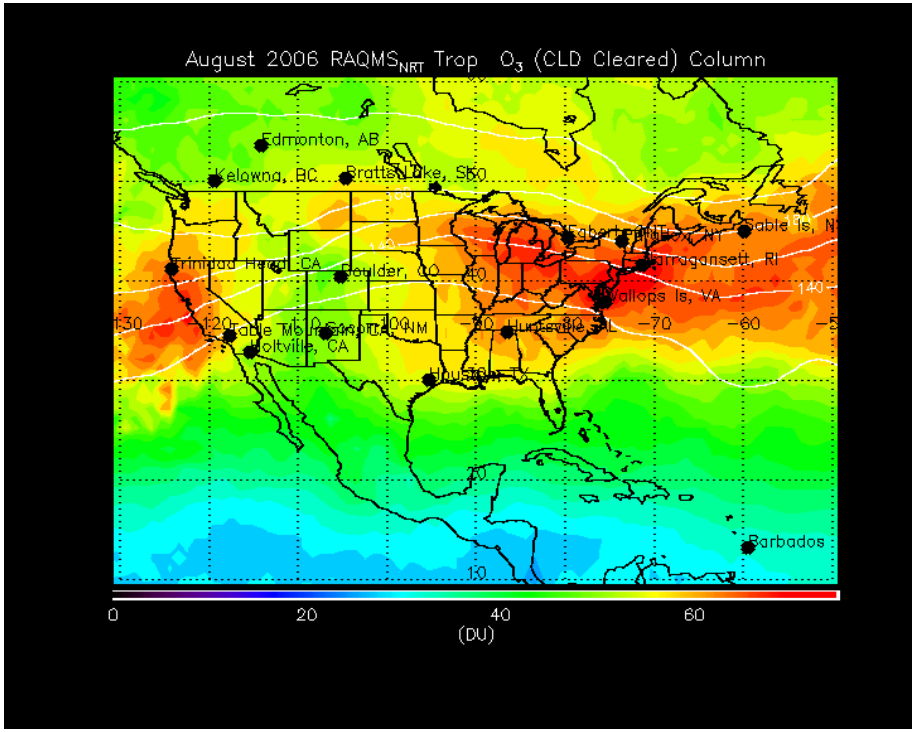
IONS-06 INTEX Ozonesonde Network Study

EC/MSC • NASA/GSFC • NOAA • JPL • LANL

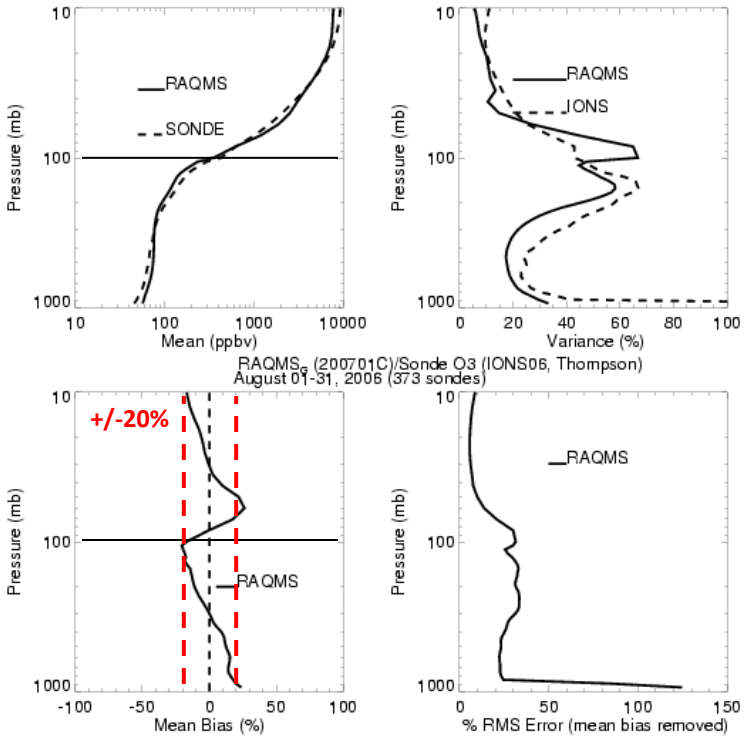
PENN STATE • HOWARDU • UAH • VALPO • URI

PI: ANNE M. THOMPSON (GFSC)

RAQMS OMI+TES Tropospheric Ozone Column (August 01-31, 2006)



Comparison of RAQMS OMI+TES reanalysis with ozonesondes during TEXAQS (373 sondes, August, 2006)

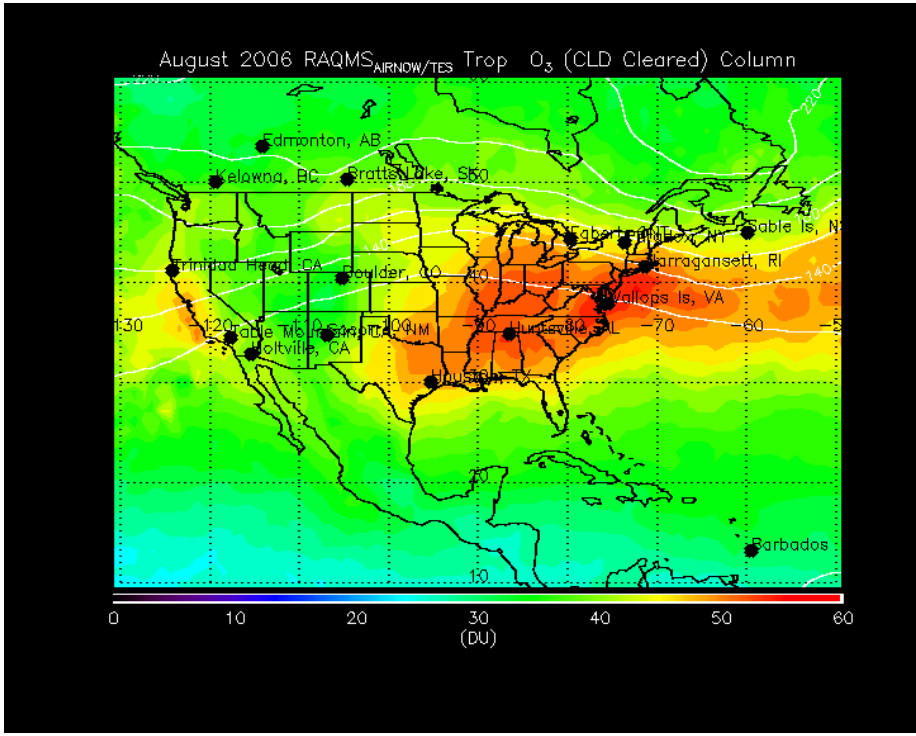


RAQMS TES/OMI Data denial Studies

Bias (%)	No Assimilation	TES Assimilation	TES+OMI Assimilation
Column	**- 8.47**	**- 3.46**	**+ 0.30**
Stratospheric	**-12.87**	**- 12.17**	**+ 0.06**
Middle Stratosphere	-17.63	- 17.60	- 5.18
Lower Stratosphere	- 4.31	- 2.40	+ 9.51
Tropospheric	**- 5.05**	**+ 3.32**	**+ 0.49**
Upper Troposphere	- 3.65	+ 2.21	- 11.31
Lower Troposphere	- 6.44	+ 4.42	+ 12.29

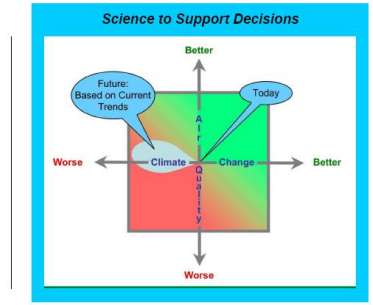
PI: ANNE M. THOMPSON GSFC

RAQMS OMI+TES Tropospheric Ozone Column (August 01-31, 2006)



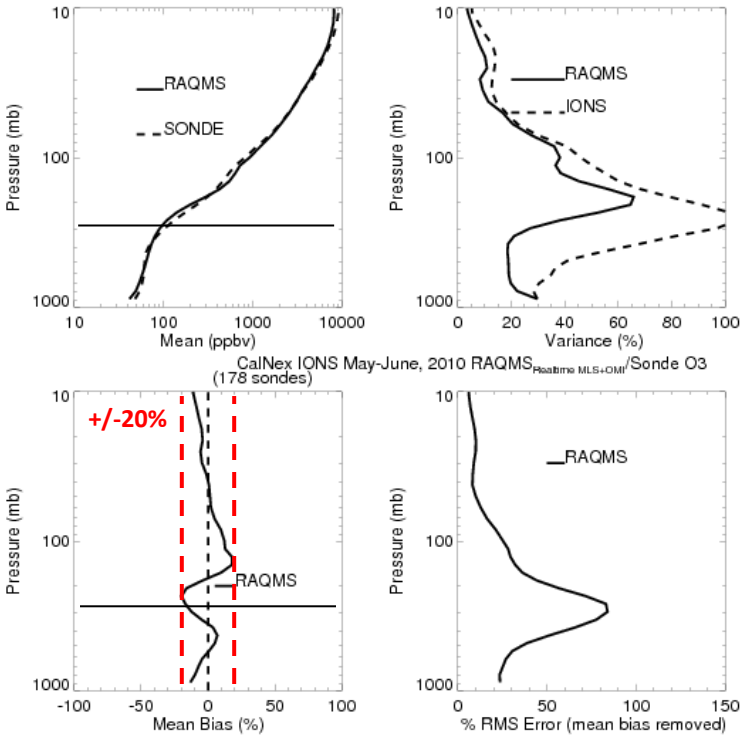
Pierce, R. B., et al. (2009), Impacts of background ozone production on Houston and Dallas, Texas, air quality during the Second Texas Air Quality Study field mission, J. Geophys. Res., 114, D00F09, doi:10.1029/2008JD011337.

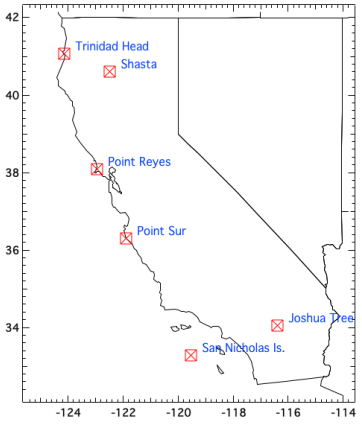
Comparison of RAQMS NRT OMI+MLS reanalysis with ozonesondes/aircraft during CalNex (178 sondes, May-June, 2010)



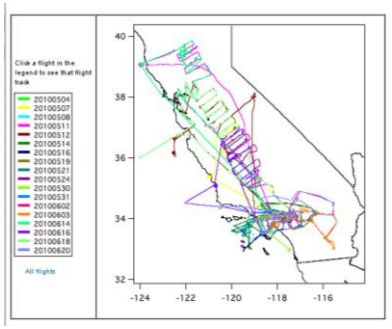
Research at the Nexus of Air Quality and Climate Change

PI: Owen Cooper (NOAA ESRL)

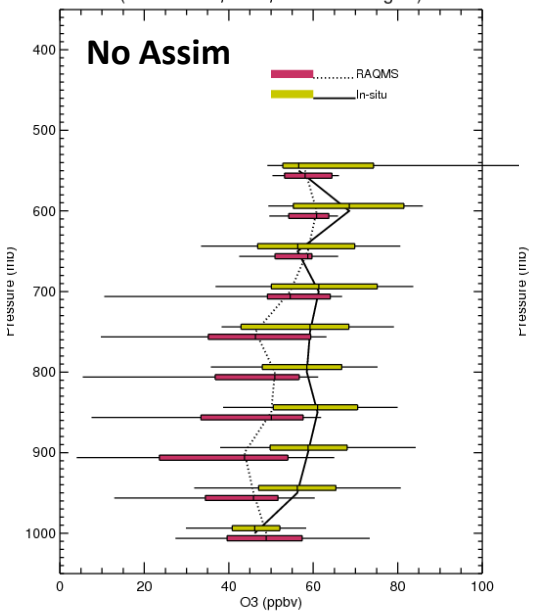




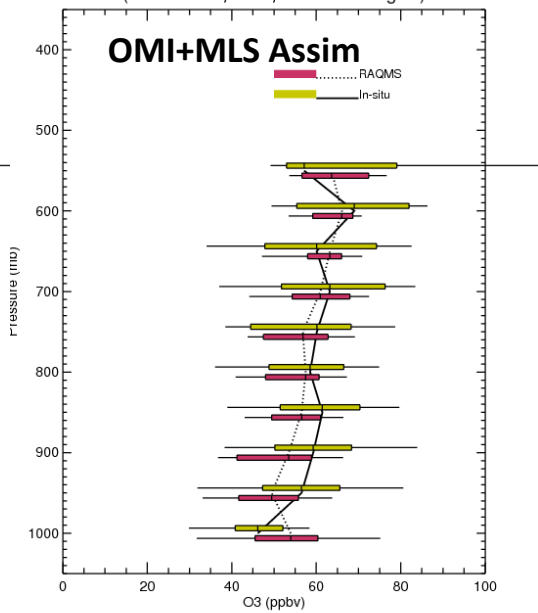
NOAA P3 Insitu O3 Measurements



RAQMS (NO ASSIM)/NOAA P3 Insitu O3 (Ryerson)
(05/04-06/20, 2010, All CalNex Flights)



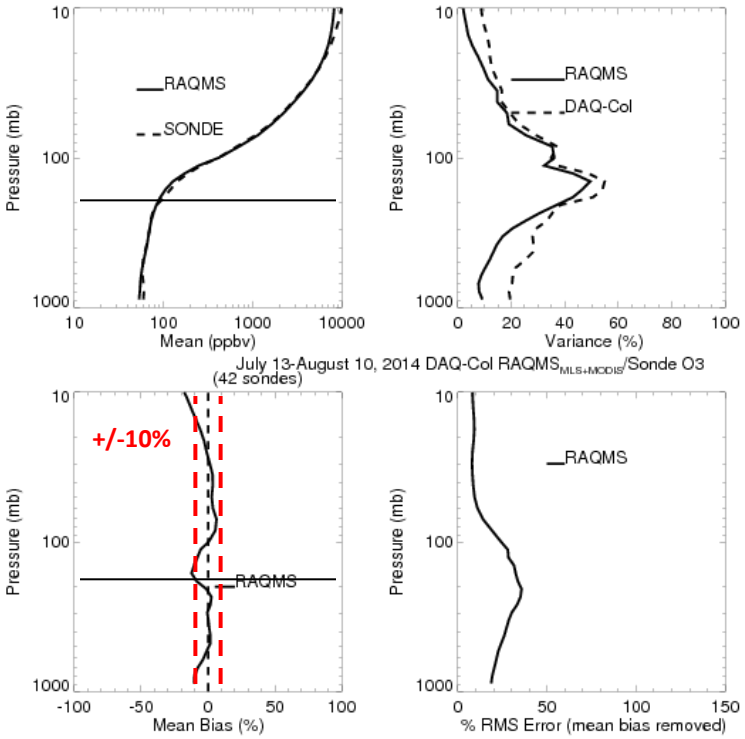
RAQMS/NOAA P3 Insitu O3 (Ryerson)
(05/04-06/20, 2010, All CalNex Flights)



Assimilation of MLS+OMI O3 retrievals results in improved agreement with airborne insitu O3 over Southern California during CalNex

Insitu O3 from Tom Ryerson, NOAA ESRL

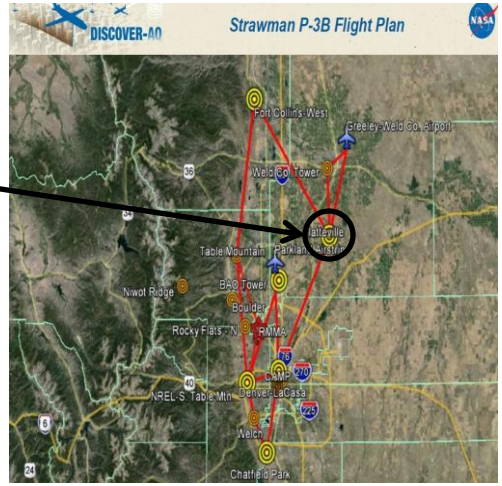
Comparison of RAQMS NRT OMI+MLS analysis with ozonesondes/aircraft during FRAPPE/DISCOVER-AQ (42 sondes, July-August, 2014)

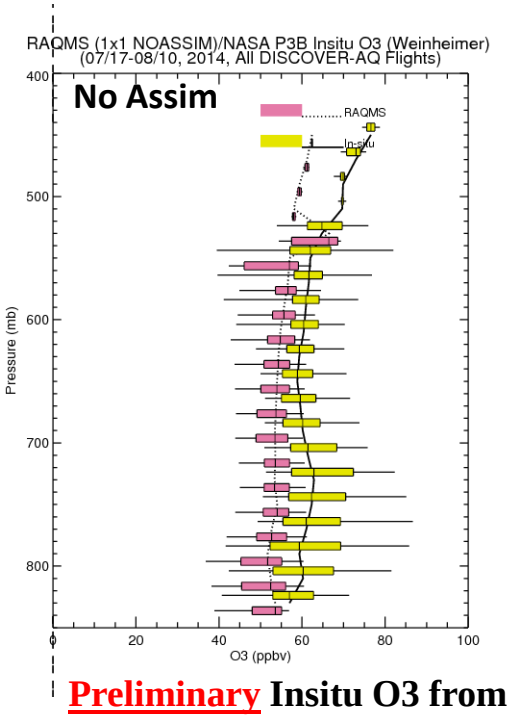


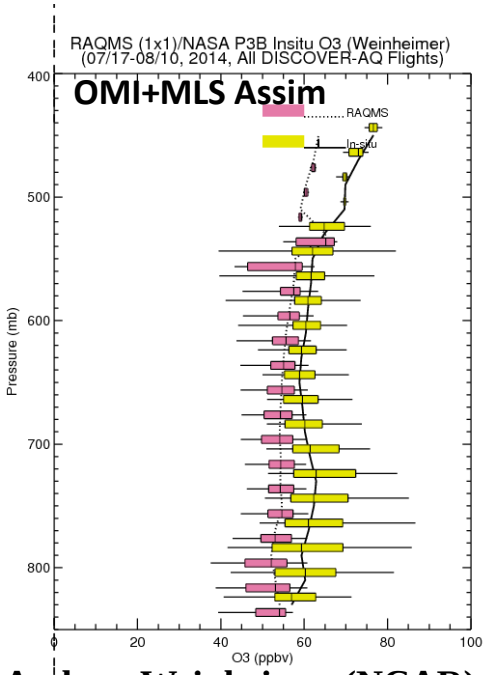
PI:ANNE M. THOMPSON GSFC

Assimilation of MLS+OMI O3 retrievals results in very slight (~1ppbv) improvement with airborne insitu O3 over the Front Range of Colorado – underestimate O3 below 700mb

Platteville ground site

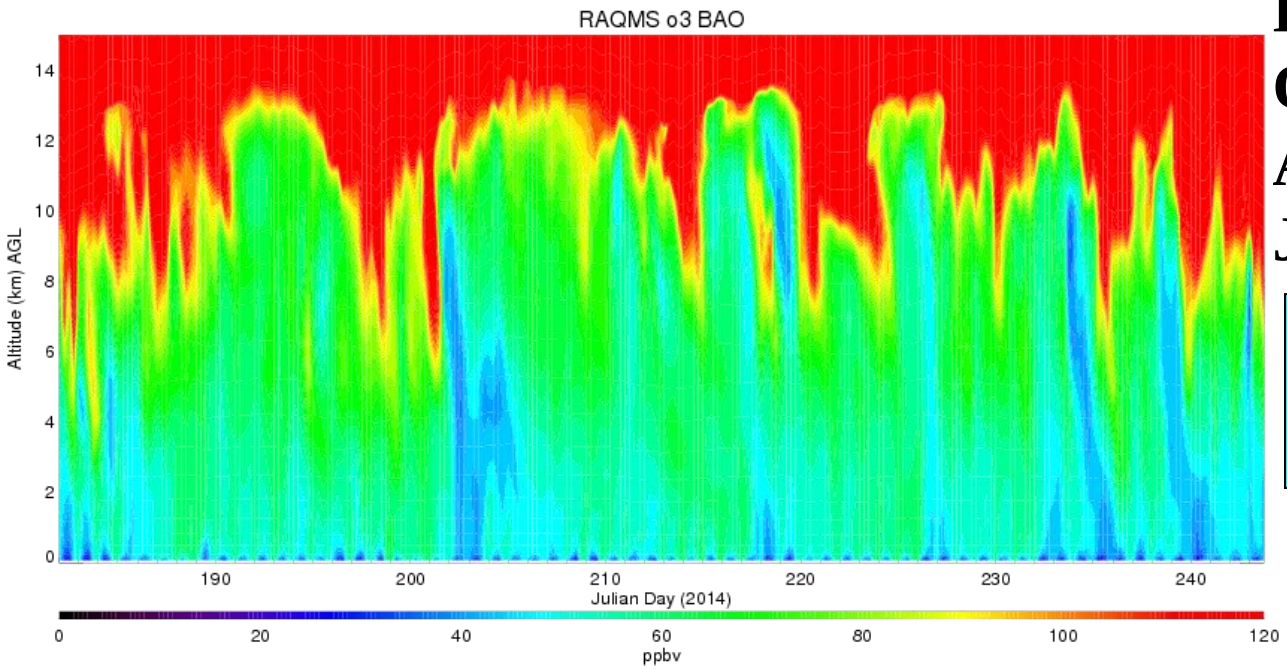


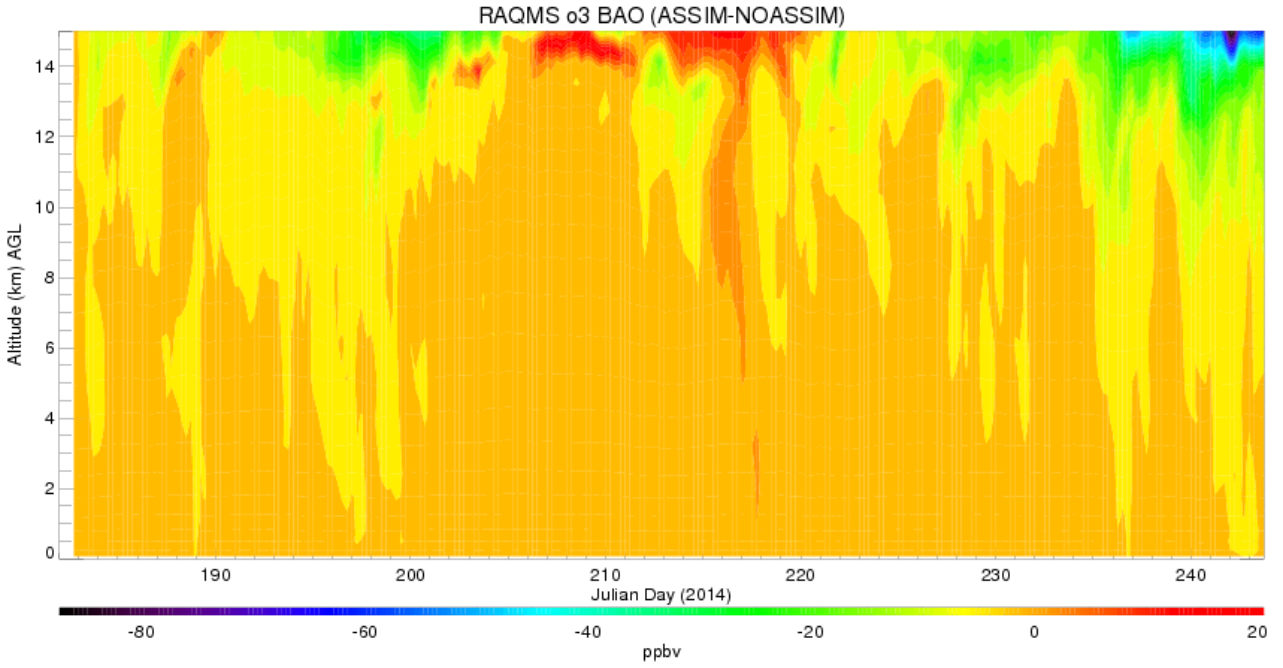




Preliminary Insitu O3 from Andrew Weinheimer (NCAR)

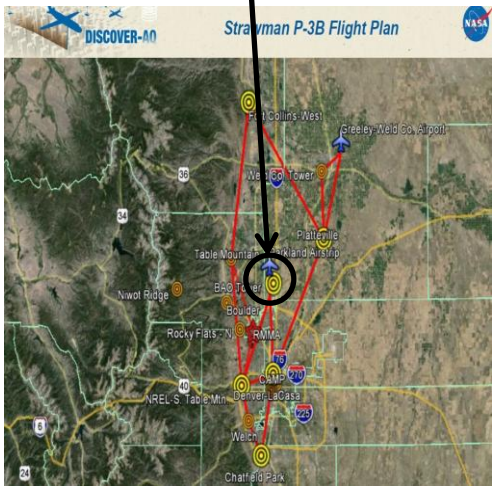
RAQMS NRT OMI+MLS O3 ASSIM vs NOASSIM July-August, 2014



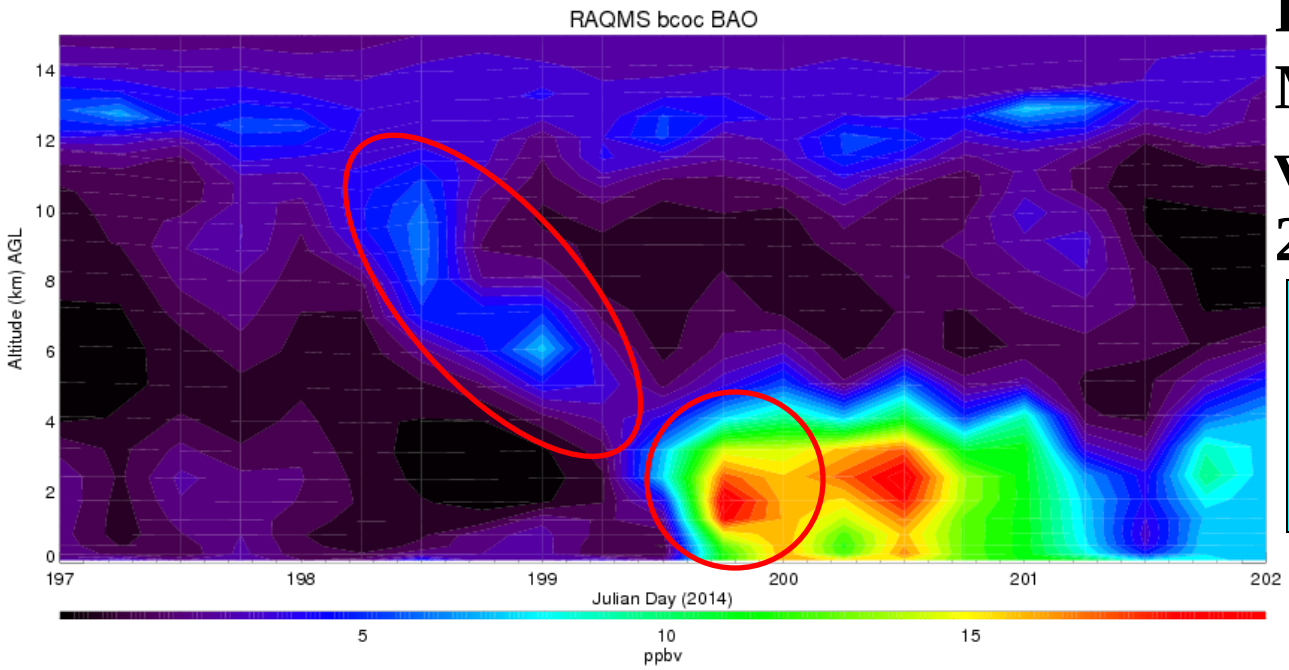


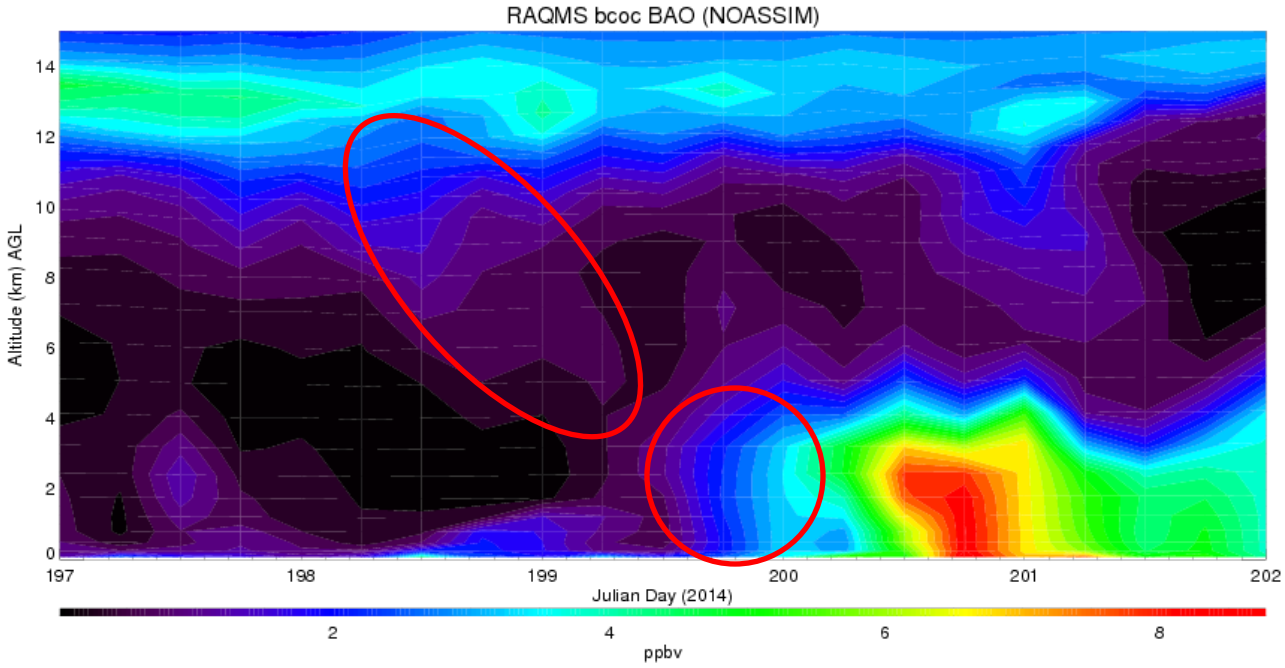
Largest impact above 12km (lower stratosphere) during FRAPPE/DISCOVER-AQ

Boulder Atmospheric Observatory (BAO)



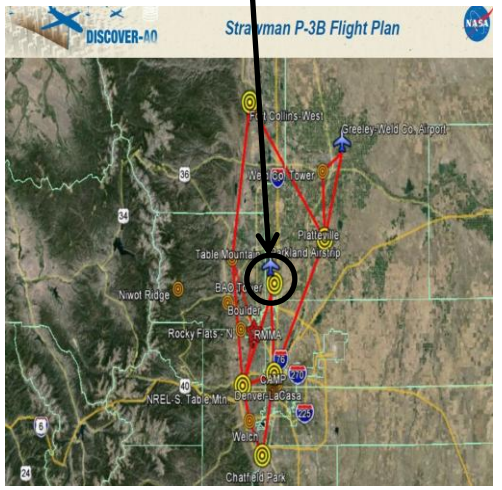
RAQMS NRT MODIS AOD ASSIM vs NOASSIM July 16-20, 2014





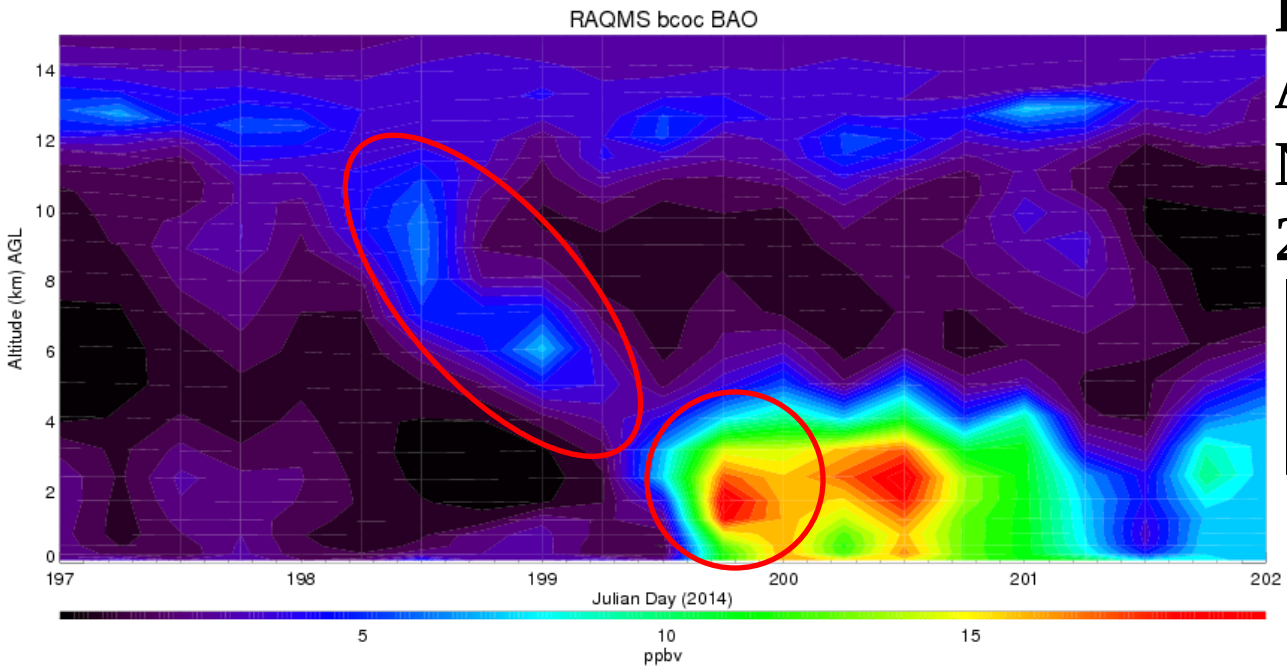
Significant impact on tropospheric Black and Organic Carbon (bcoc) during FRAPPE/DISCOVER-AQ

Boulder Atmospheric Observatory (BAO)

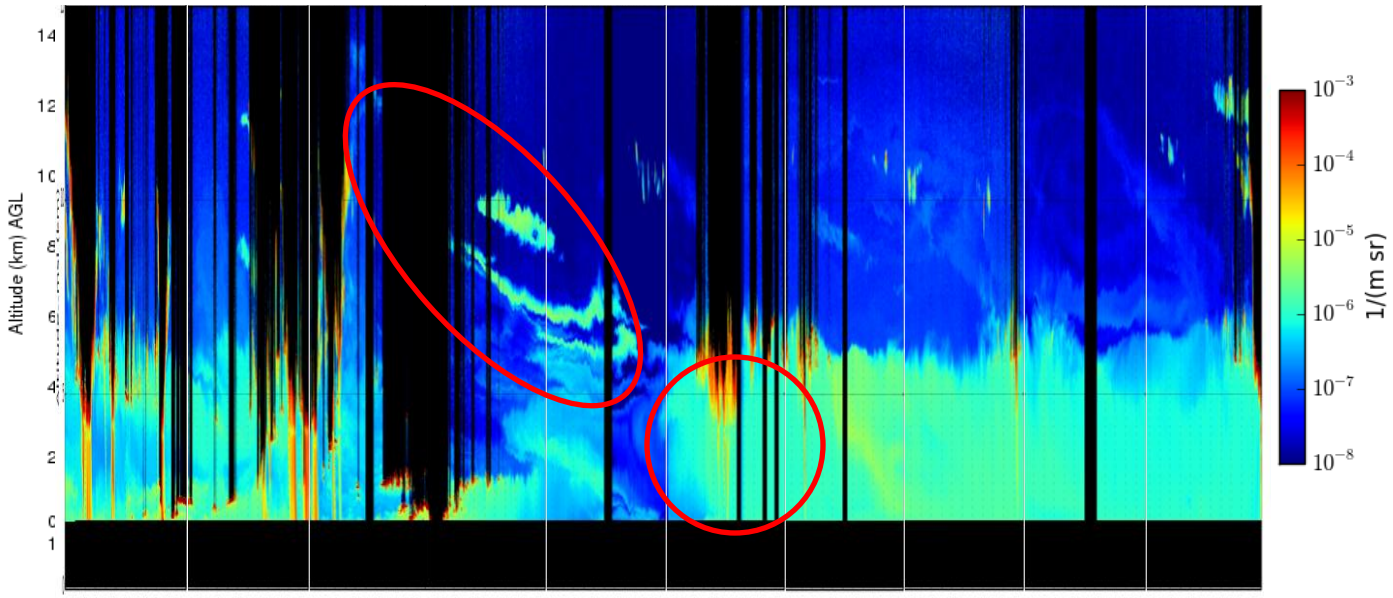


RAQMS MODIS AOD ASSIM vs NOASSIM July 16-20, 2014

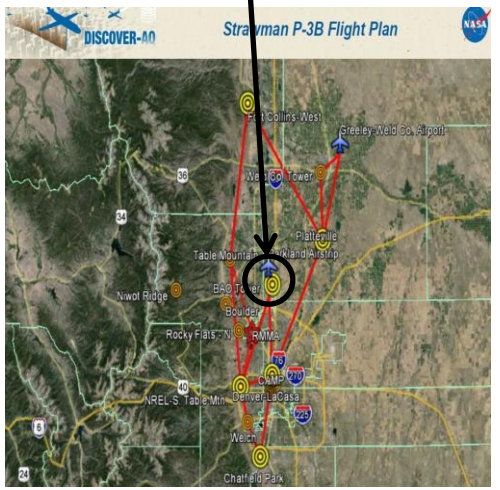
Good qualitative agreement with ground based HSRL aerosol backscatter at BAO



High Spectral Resolution Lidar (HSRL)



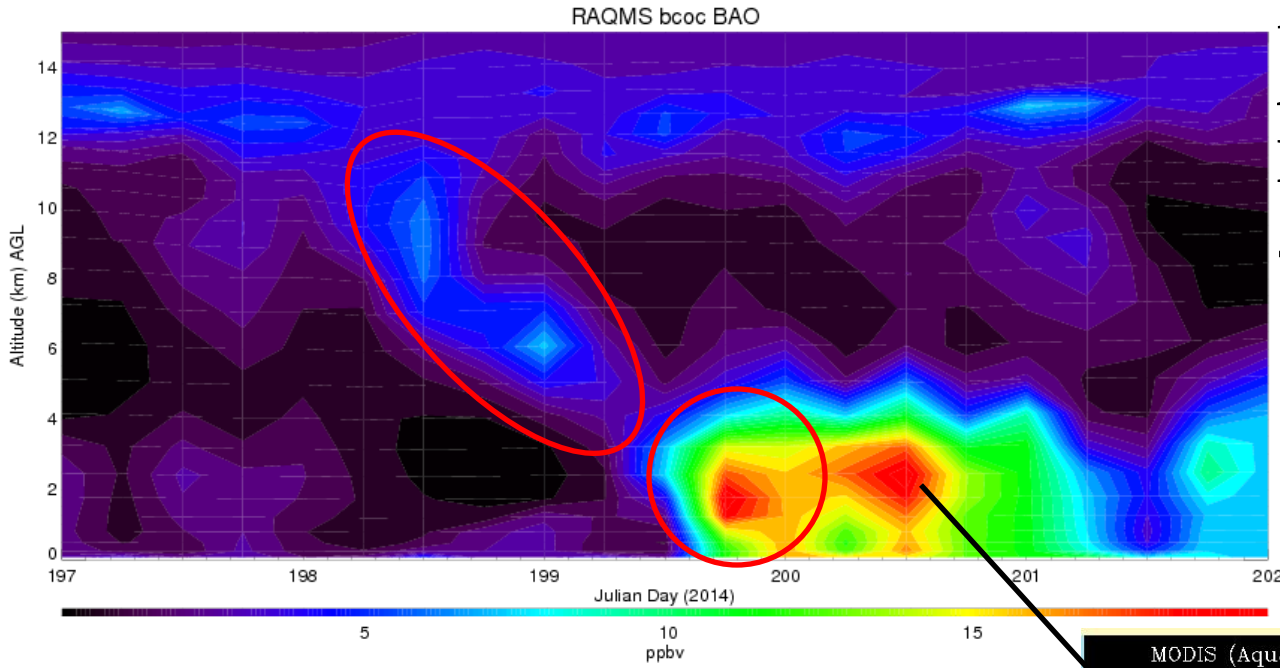
Boulder Atmospheric Observatory (BAO)



[HSRL Lidar (Ed Eloranta, UW-Madison) http://lidar.ssec.wisc.edu/syst/ahsrl/ahsrl_data.htm](http://lidar.ssec.wisc.edu/syst/ahsrl/ahsrl_data.htm)

RAQMS MODIS AOD ASSIM vs NOASSIM July 16-20, 2014

Captures transport of Pacific NW and Canadian wildfire smoke into Colorado



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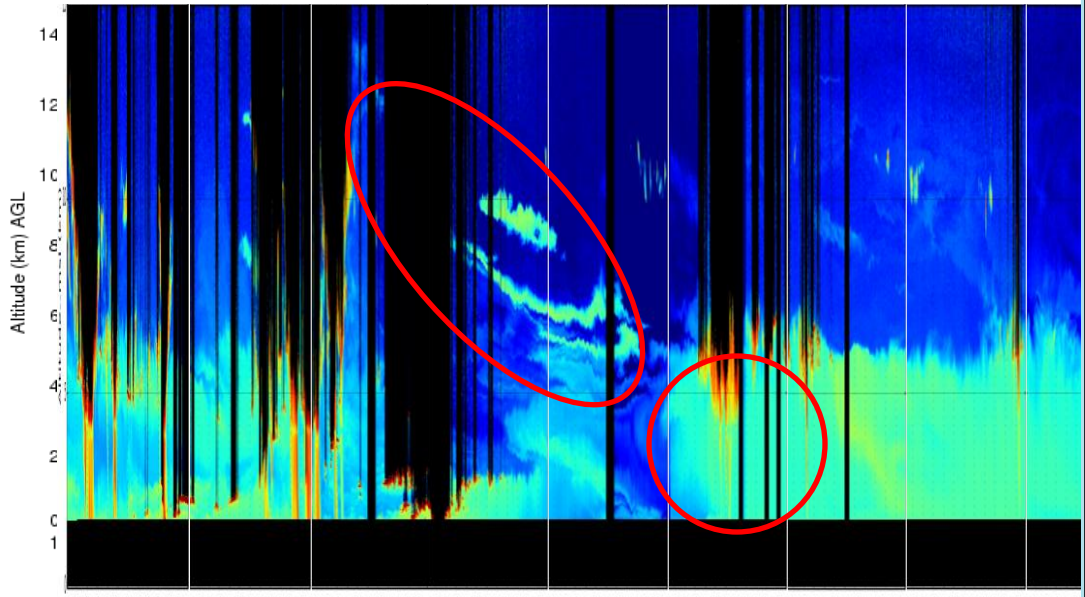
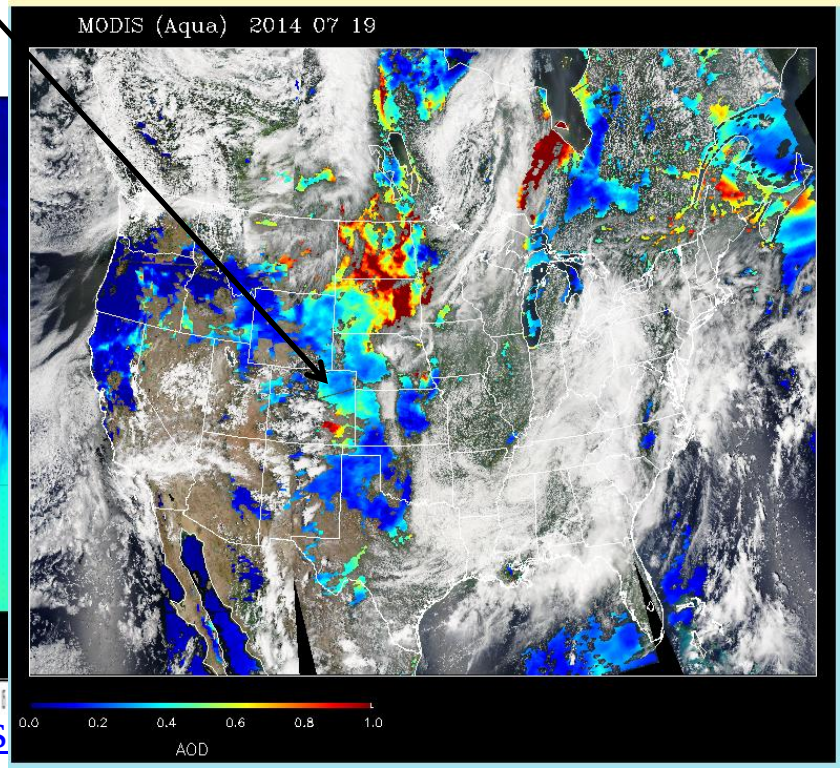
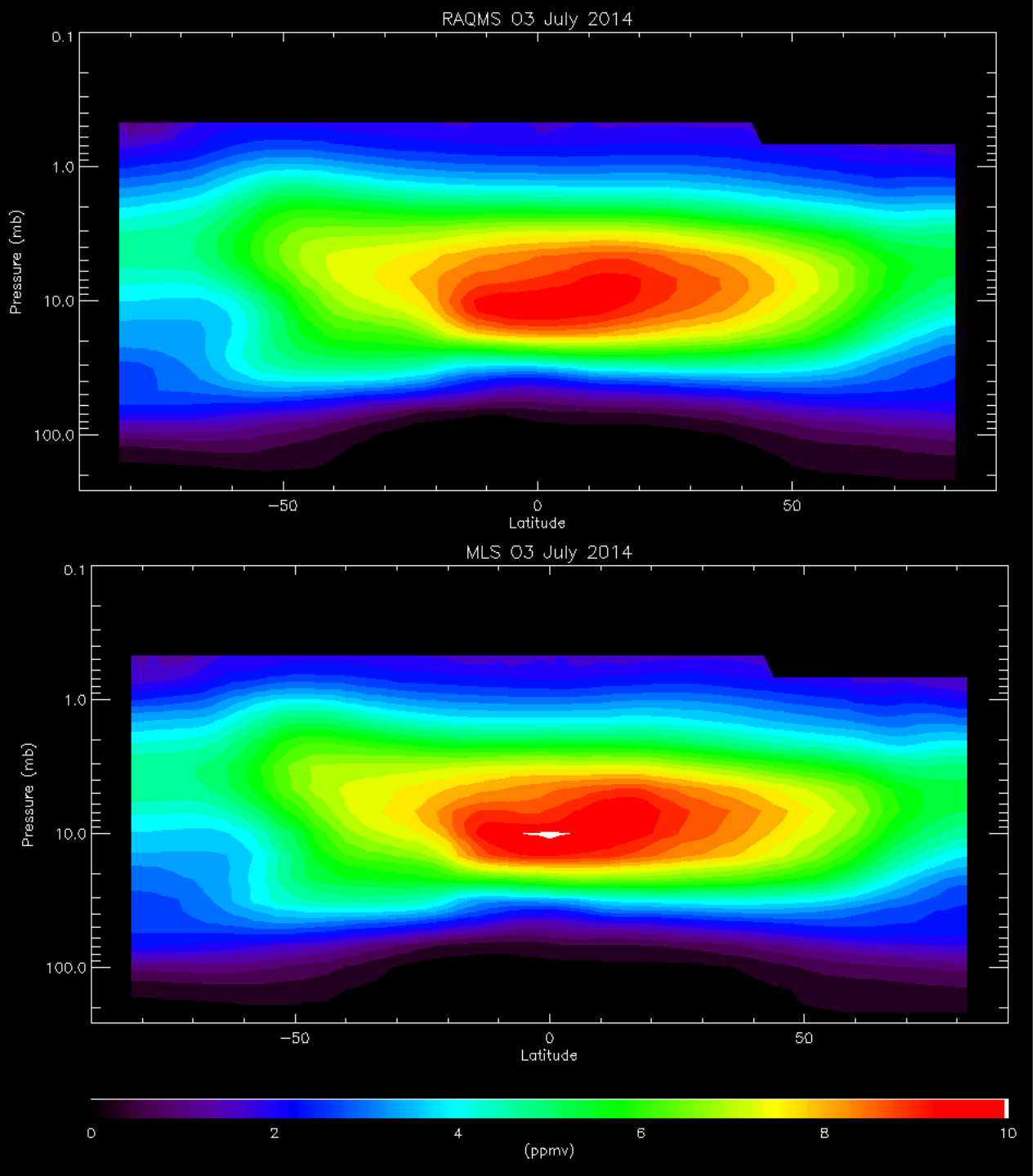




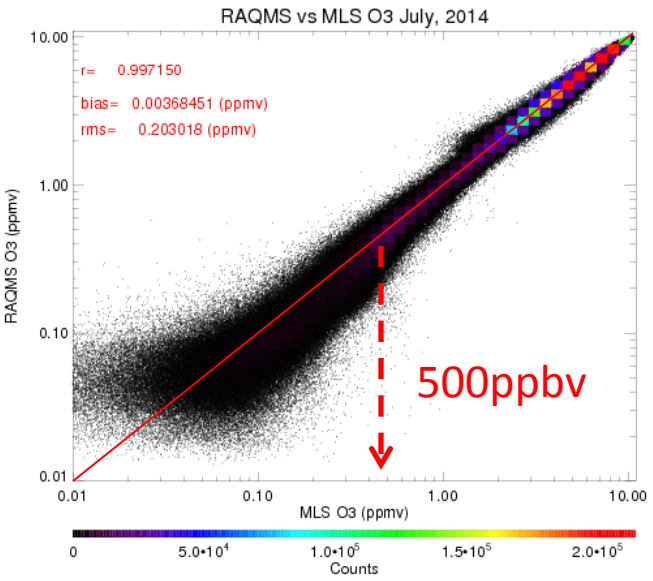
HSRL Lidar (Ed Eloranta, UW-Madison) http://lidar.ss

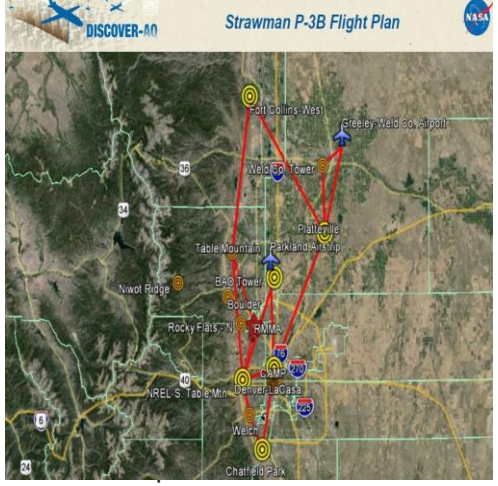
Comparison of RAQMS with MLS Global O3 July 2014



Currently only assimilating NRT MLS O3 above 50mb

Need to determine minimum MLS O3 mixing ratio for reanalysis

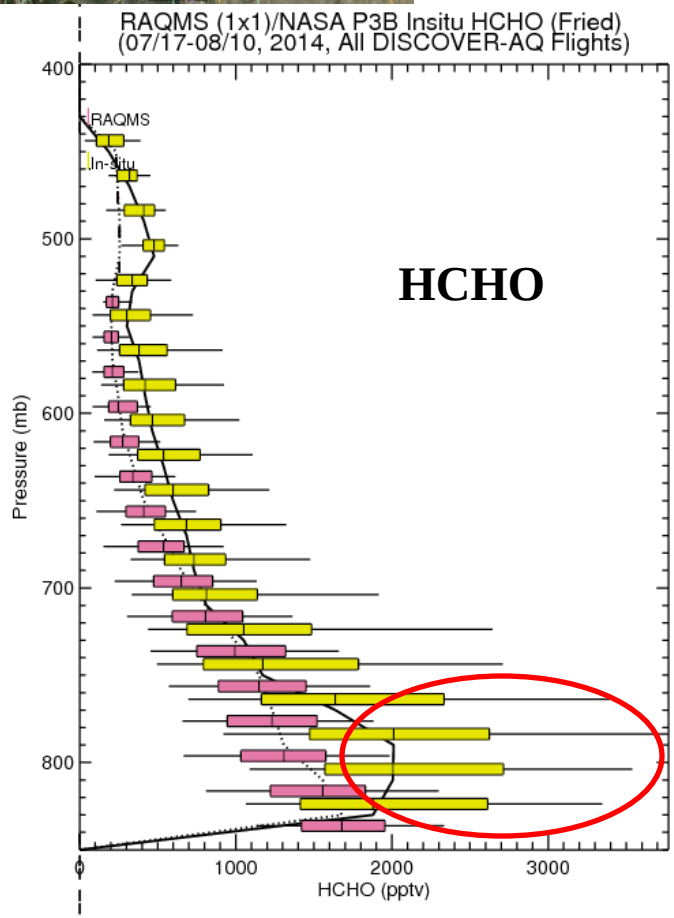




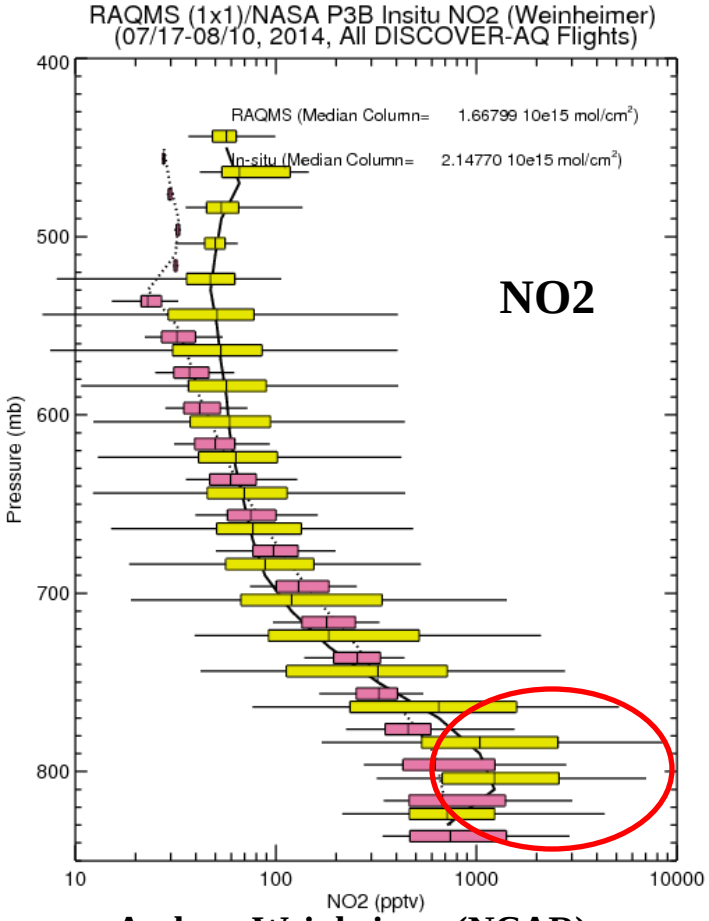
Comparison of RAQMS with NASA P3 during FRAPPE/DISCOVER-AQ

(Preliminary)

Systematic underestimate of HCHO and NO2 below 750mb over Front Range of Colorado during July-August, 2014 – does not resolve strong local urban and Oil and Gas sources

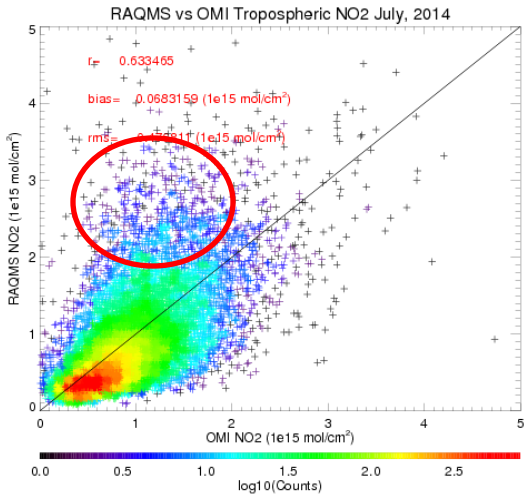


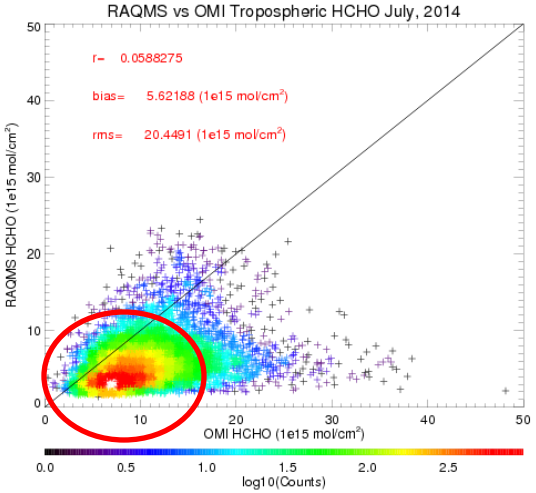
Alan Fried (Univ Colorado)

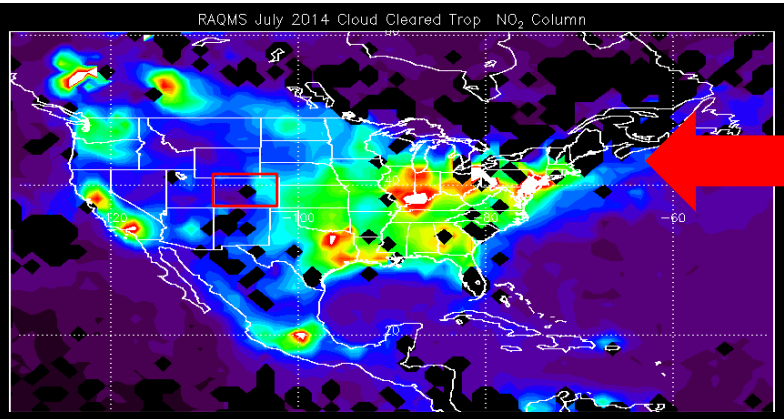


Andrew Weinheimer (NCAR)

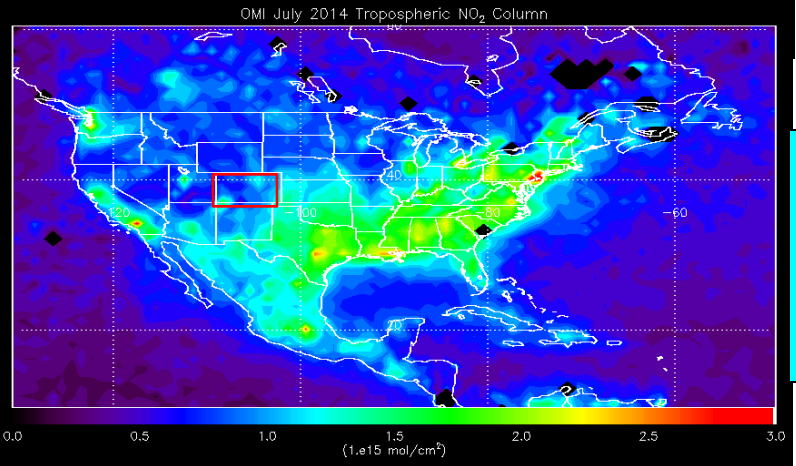
Comparison of RAQMS with OMI Tropospheric NO2 and HCHO Continental US July 2014

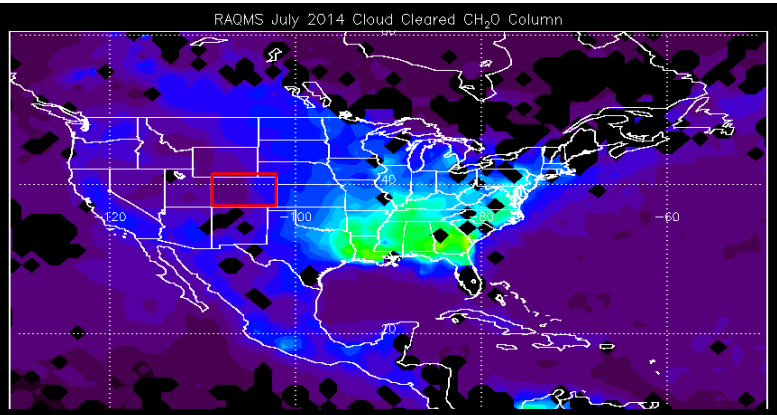




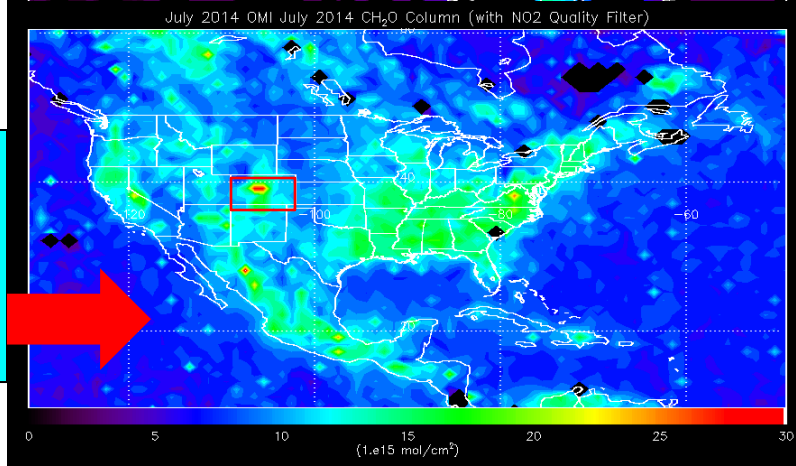


Overestimate urban and wildfire NO2

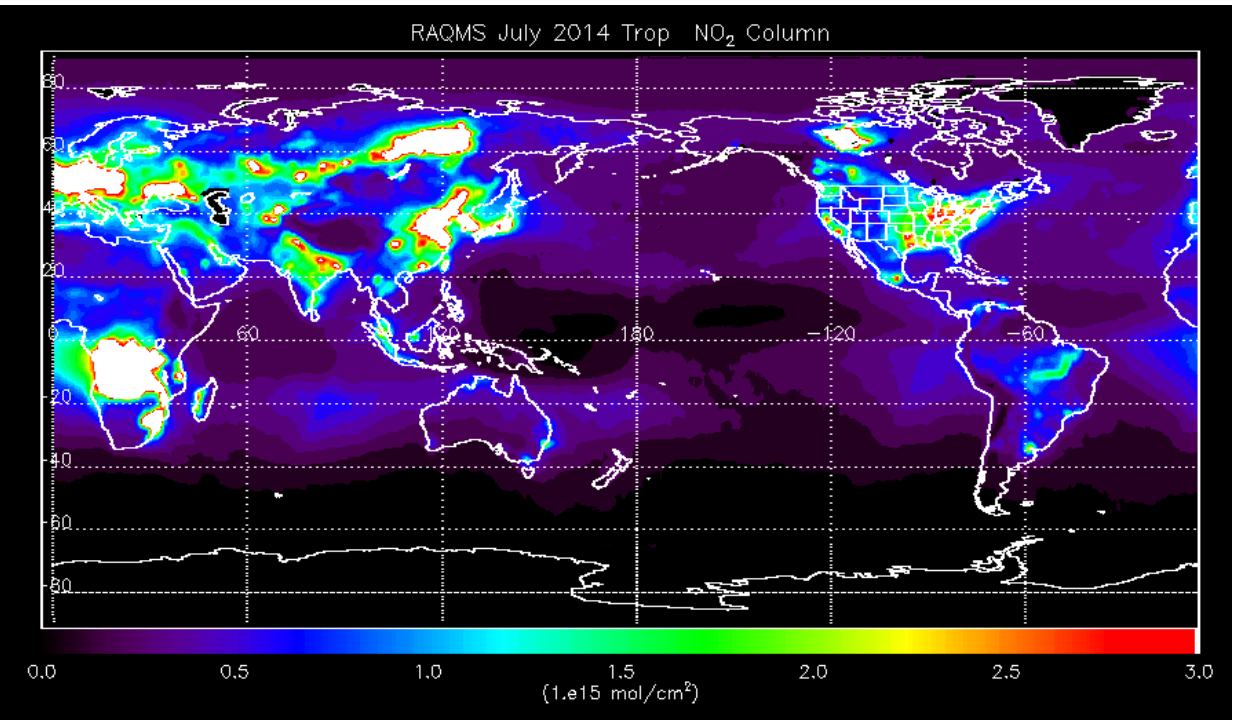


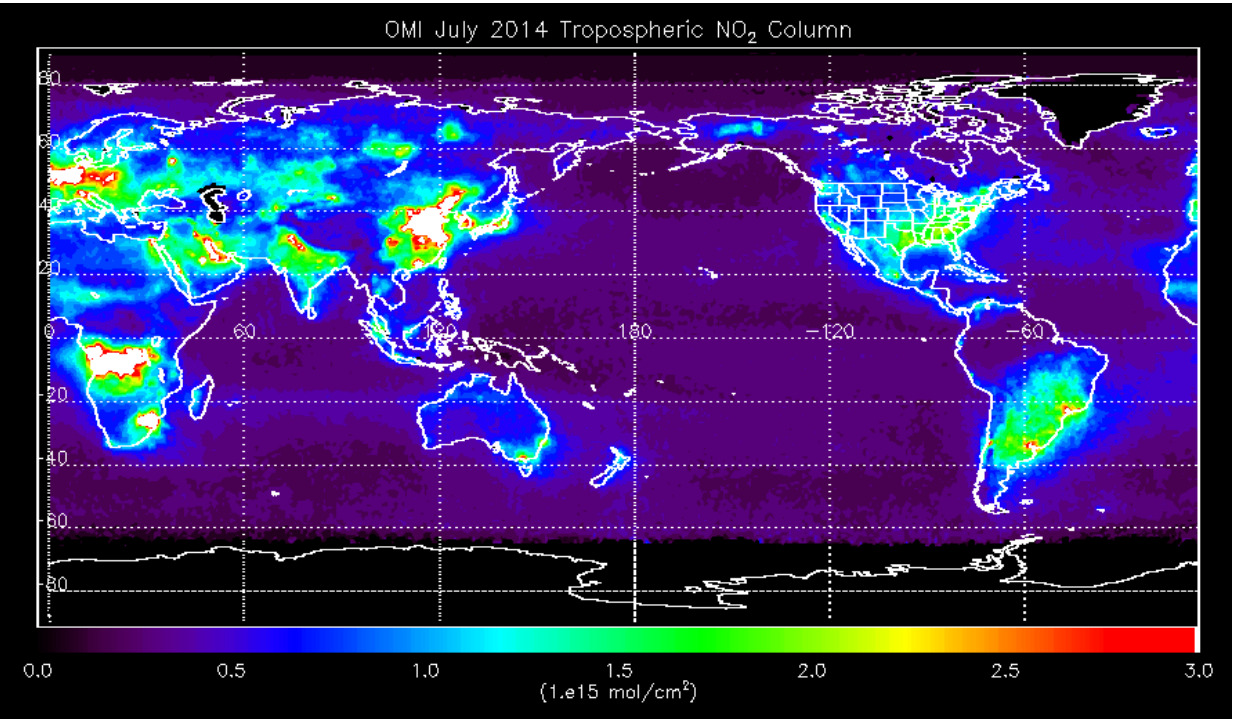


Underestimate western and background HCHO

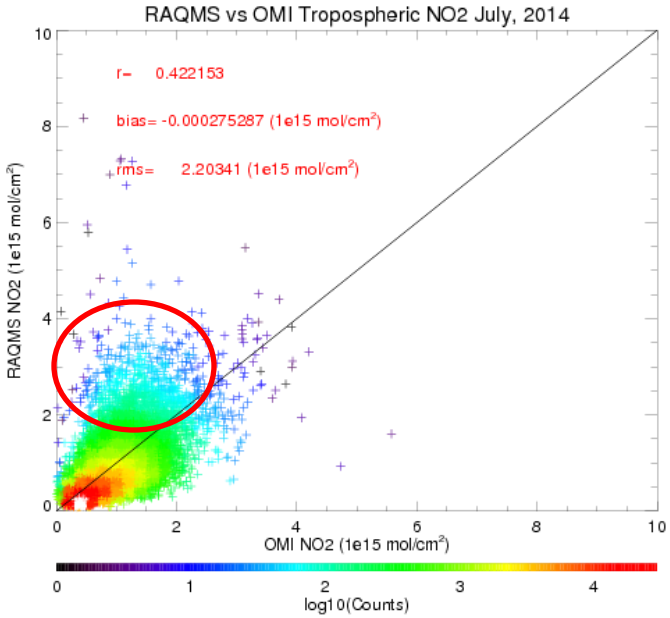


Comparison of RAQMS with OMI Global Tropospheric NO2 July 2014

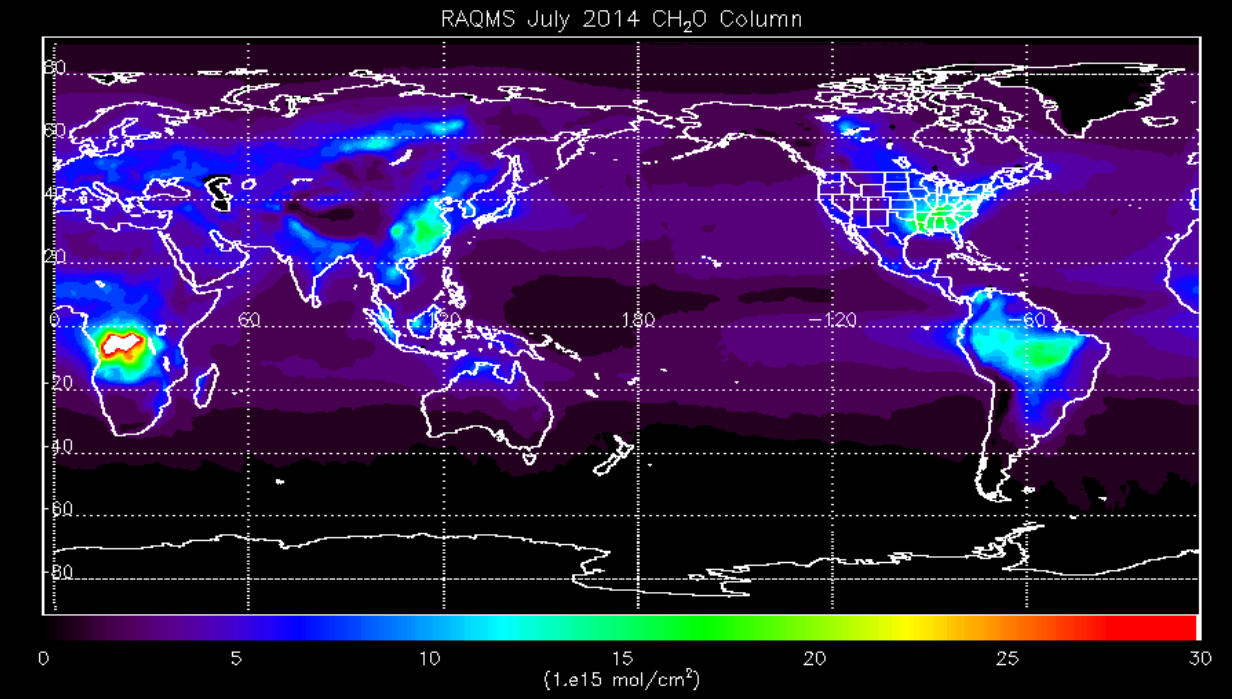


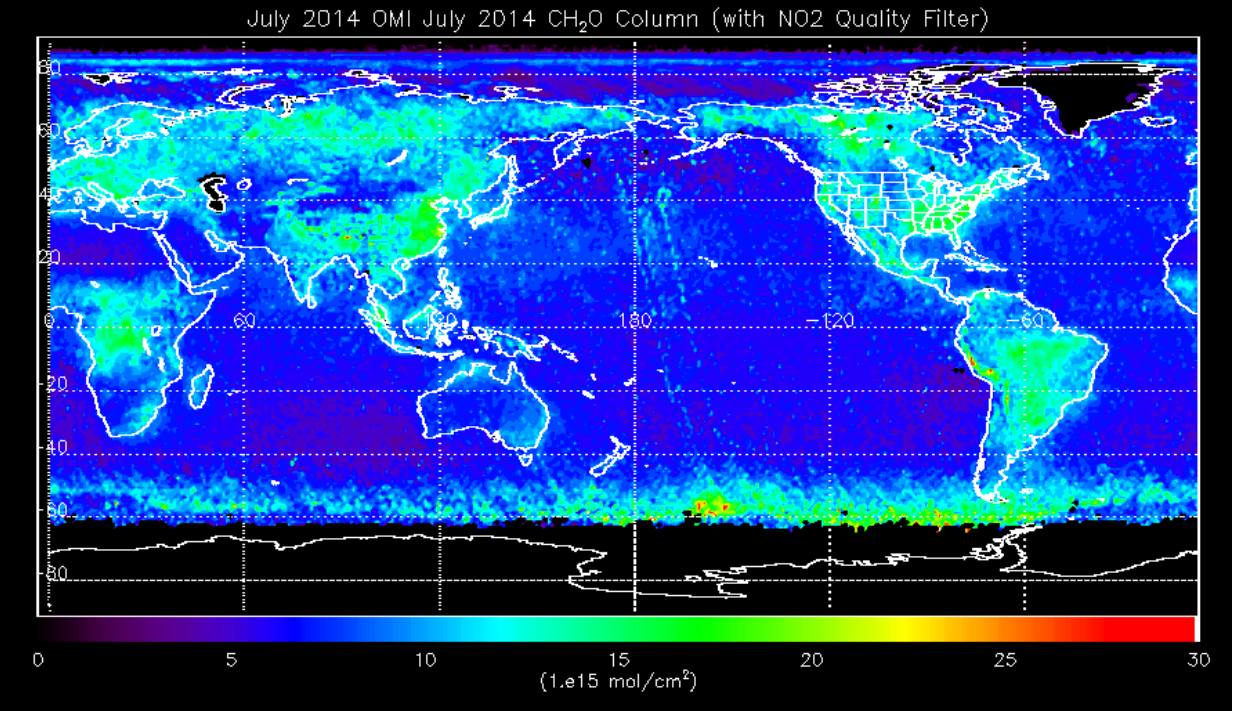


Overestimate urban and wildfire NO2



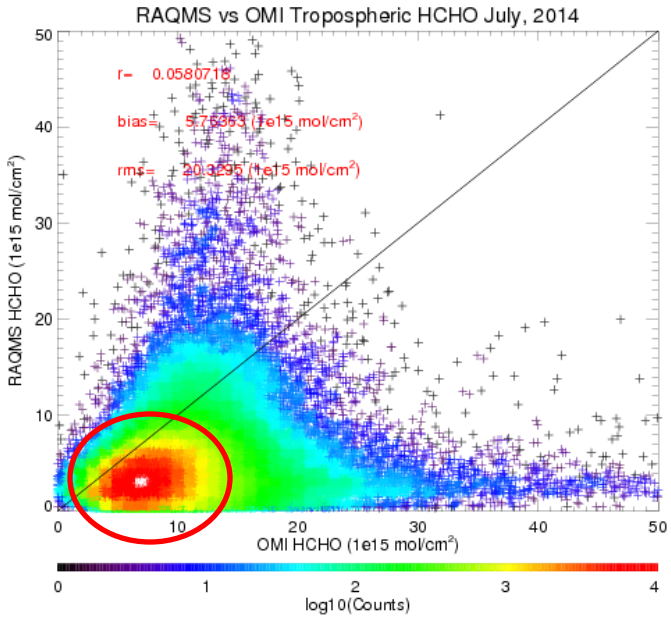
Comparison of RAQMS with OMI HCHO July 2014





Underestimate background HCHO

Retrieval artifacts apparent in Southern Hemisphere mid latitudes

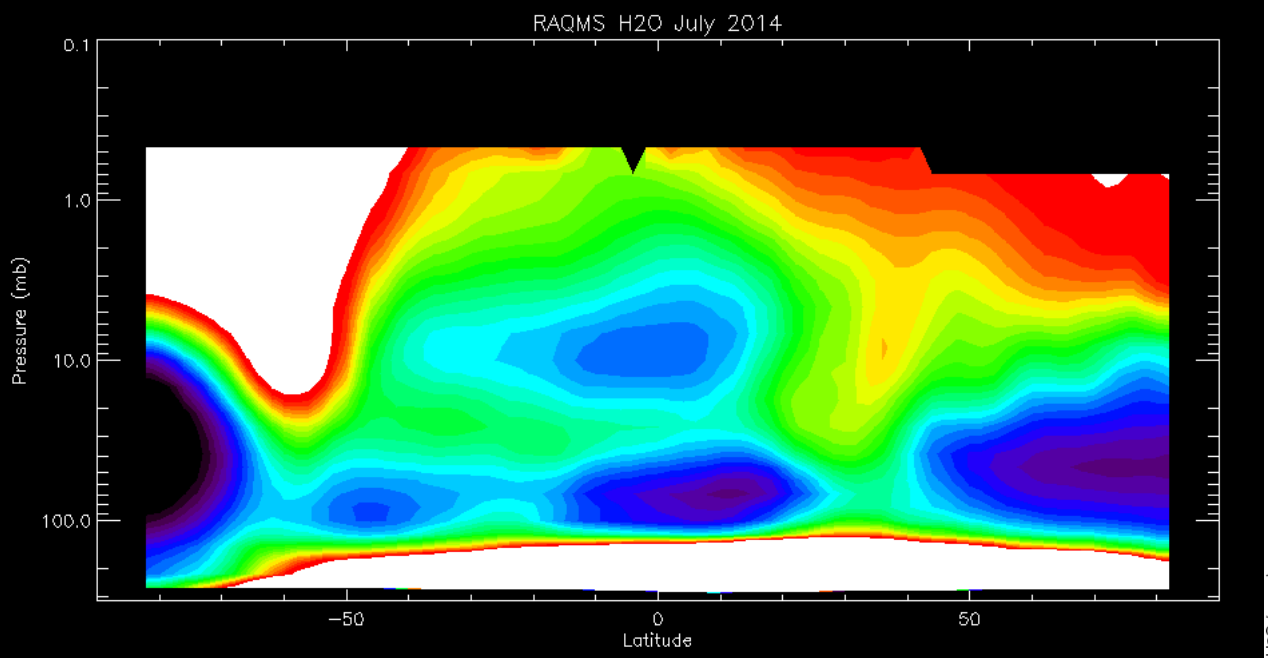


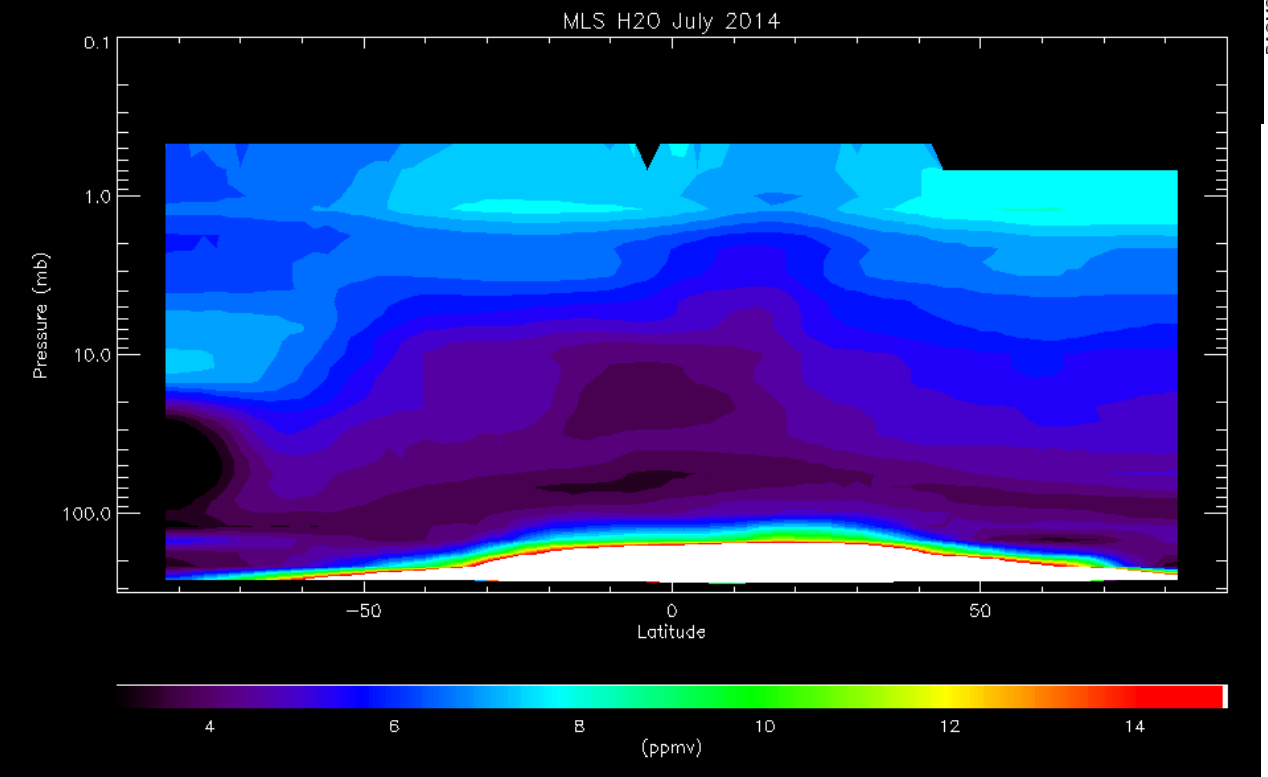
Summary

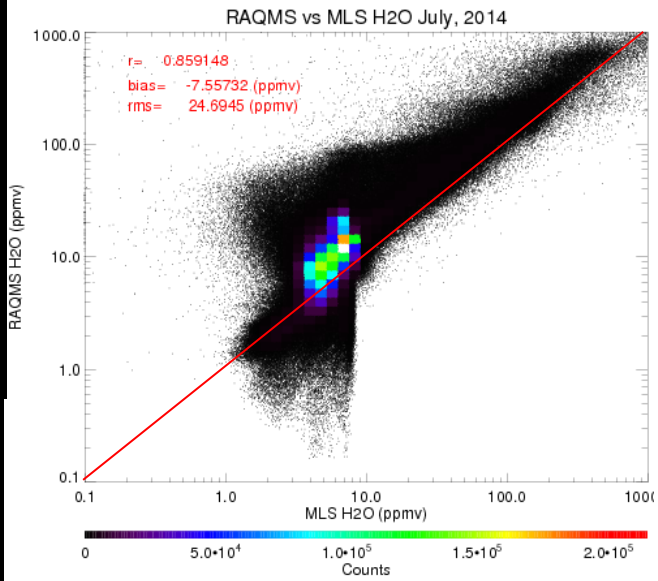
- **Data denial experiments using Aura OMI, TES, and MLS O3 and MODIS Terra/Aqua aerosol optical depth retrievals demonstrate the utility of assimilating satellite measurements for air quality applications *– improved constraints on lateral boundary conditions for regional AQ models* (Yates, et al. ACP, 2013, Huang et al, JGR, 2013, Fiore et al., EM, 2014)**

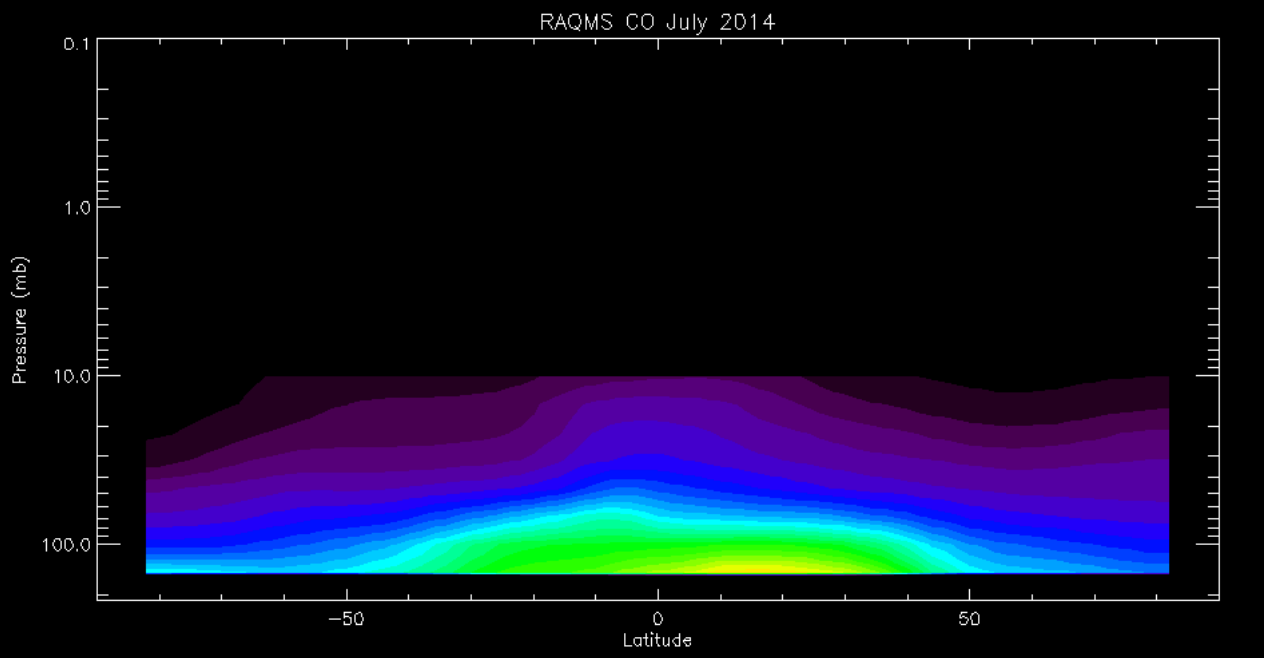
- **We intend to extend this capability to other OMI, MLS, and TES (or AIRS) trace gas retrievals using state of the science 3D variational analysis approaches (GSI) to provide the air quality community with a multi-year global chemical and aerosol reanalysis using NASA Aura and A-Train measurements.**

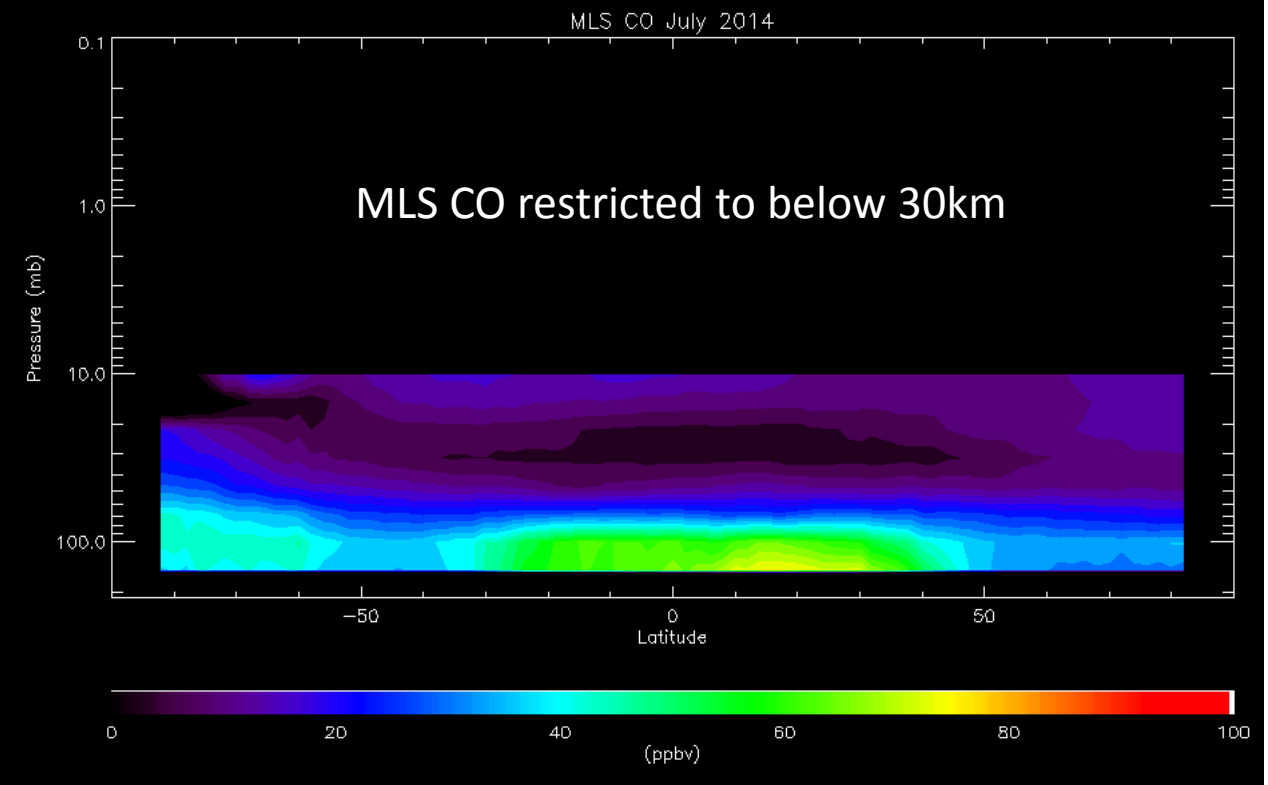
Extra Slides

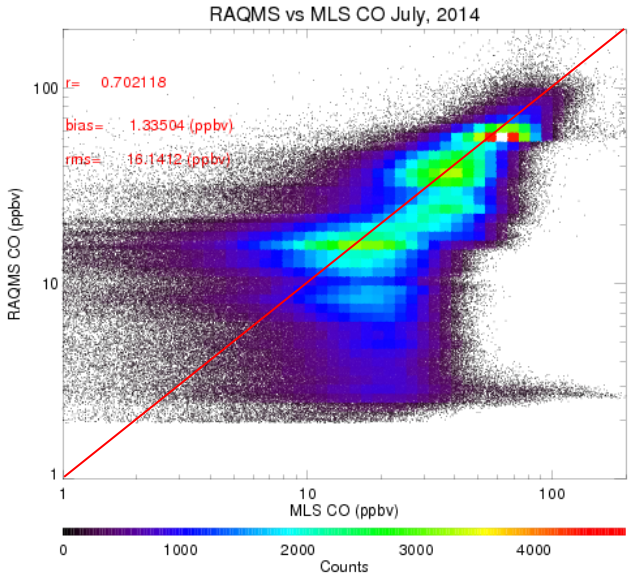

RAQMS H2O July 2014
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude

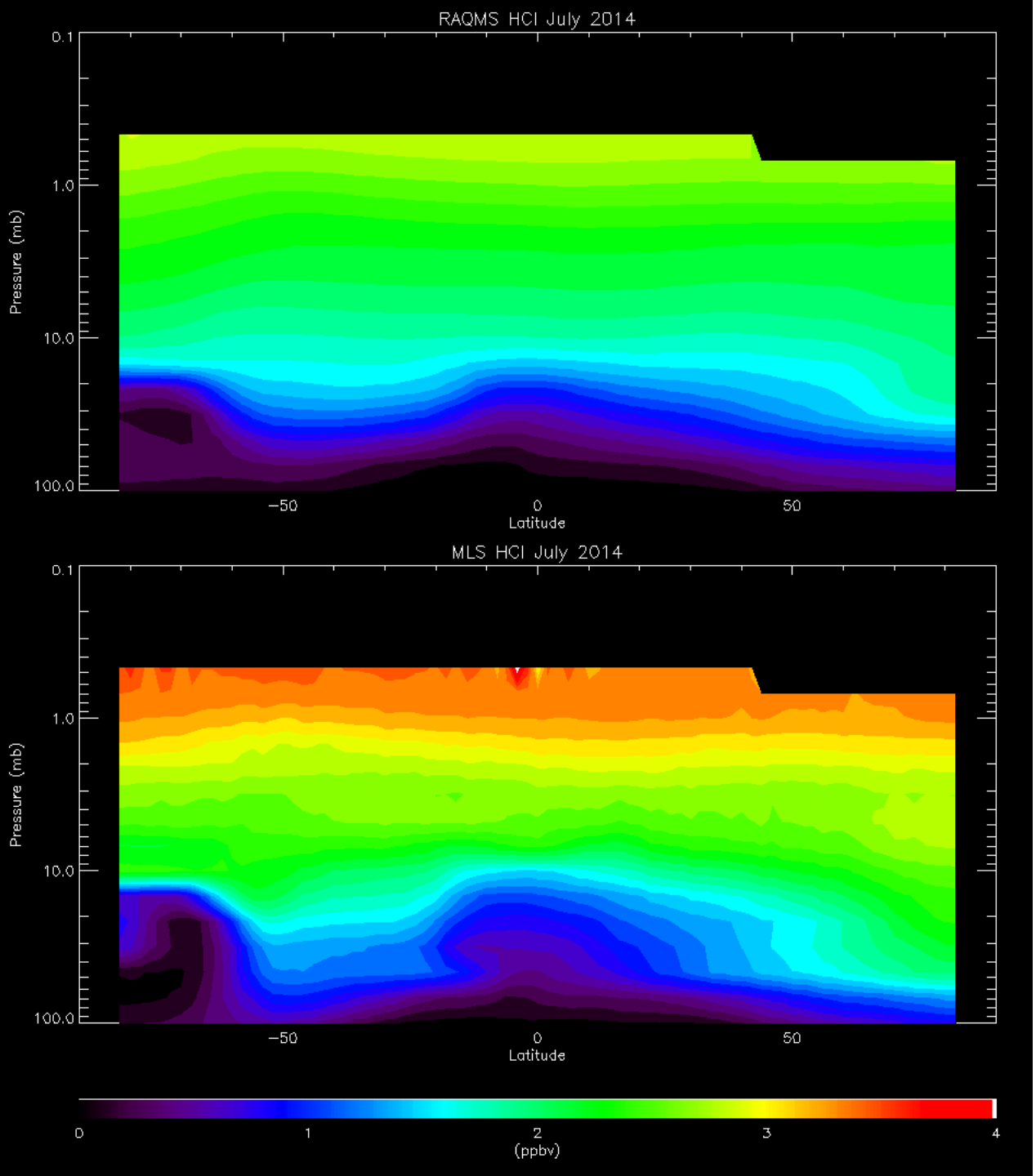

MLS H2O July 2014
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude
4
6
8
10
12
14
(ppmv)

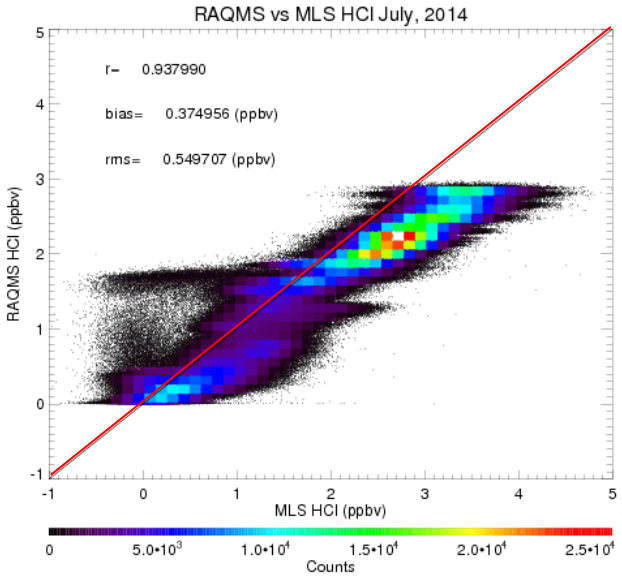

RAQMS vs MLS H2O July, 2014
r= 0.859148
bias= -7.55732 (ppmv)
rms= 24.6945 (ppmv)
RAQMS H2O (ppmv)
1000.0
100.0
10.0
1.0
0.1
0.1
1.0
10.0
100.0
MLS H2O (ppmv)
0
5.0•10^4
1.0•10^5
1.5•10^5
2.0•10^5
Counts

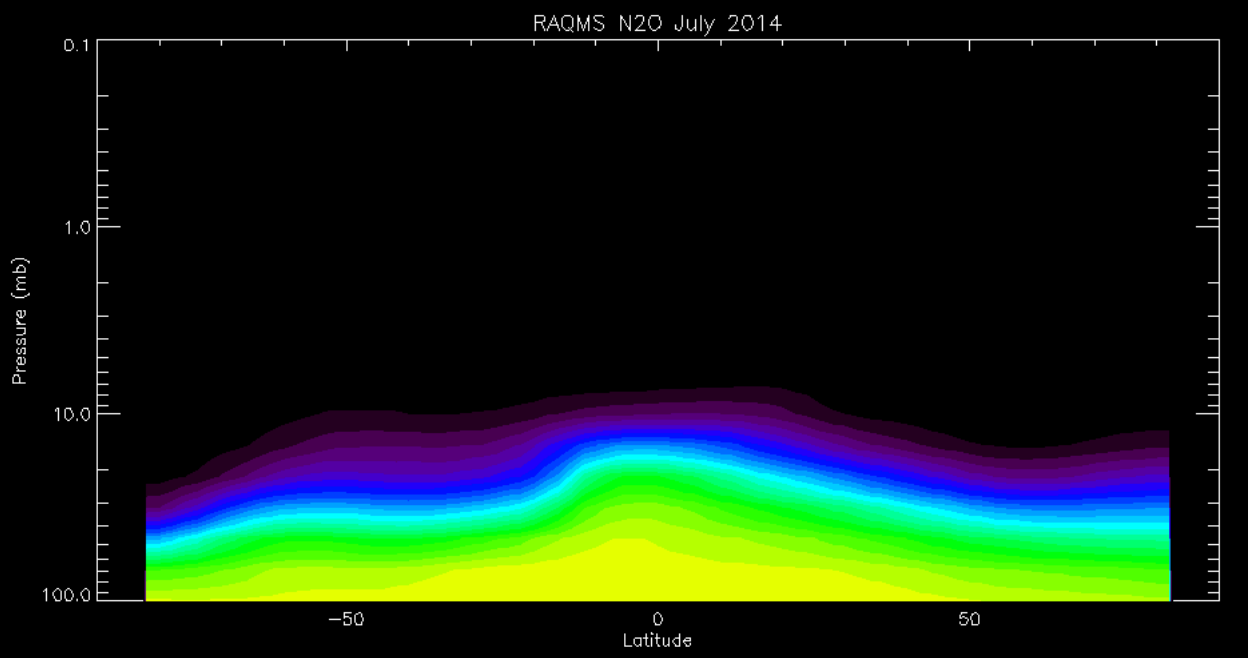

RAQMS CO July 2014
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude

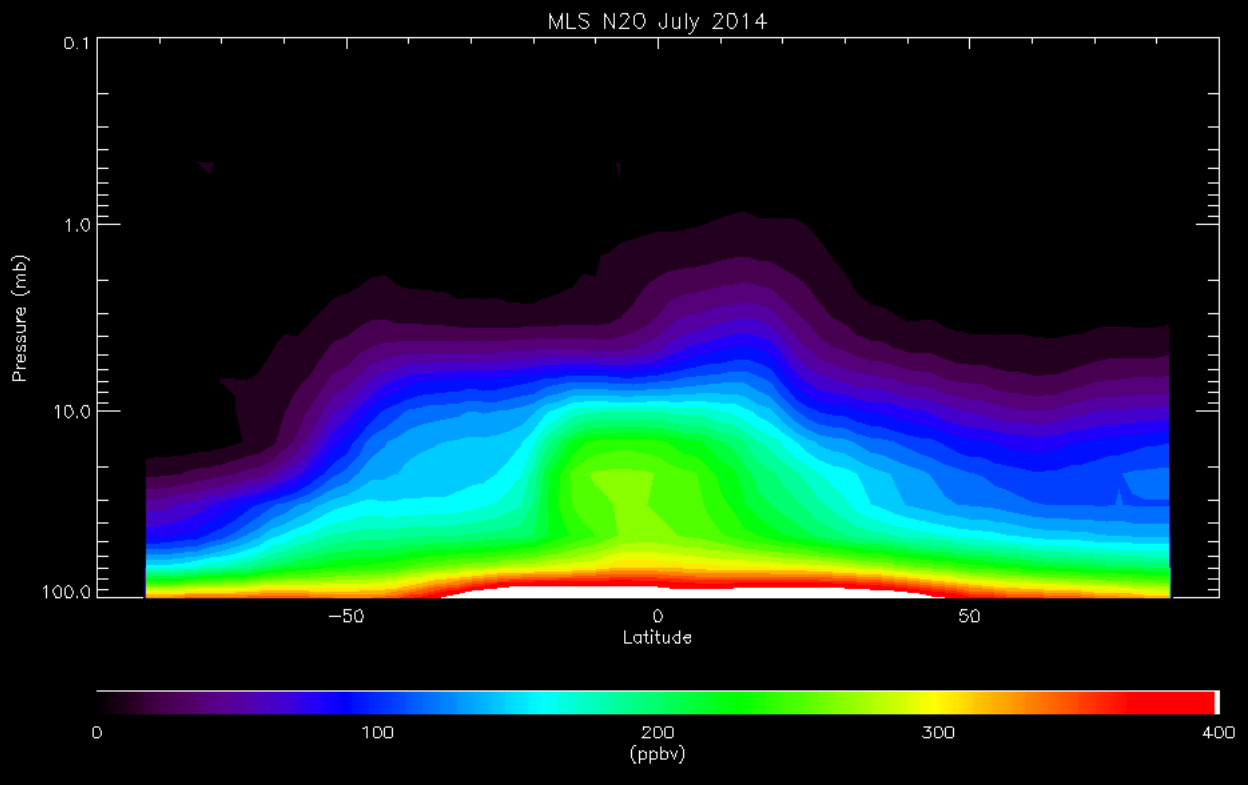

MLS CO July 2014
MLS CO restricted to below 30km
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude
0
20
40
60
80
100
(ppbv)

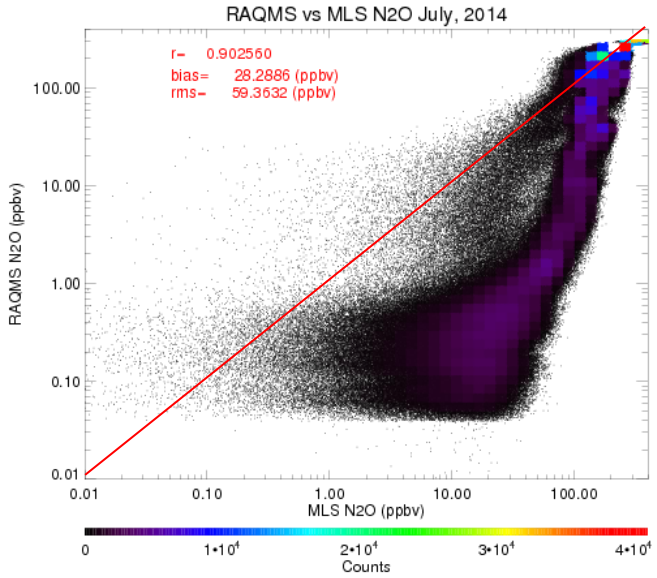

RAQMS vs MLS CO July, 2014
r= 0.702118
bias= 1.33504 (ppbv)
rms= 16.1412 (ppbv)
RAQMS CO (ppbv)
100
10
1
1
10
100
MLS CO (ppbv)
0
1000
2000
3000
4000
Counts


RAQMS HCl July 2014
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude
MLS HCl July 2014
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude
0
1
2
3
4
(ppbv)


RAQMS vs MLS HCl July, 2014
r= 0.937990
bias= 0.374956 (ppbv)
rms= 0.549707 (ppbv)
RAQMS HCl (ppbv)
MLS HCl (ppbv)
-1
0
1
2
3
4
5
0
5.0•10^3
1.0•10^4
1.5•10^4
2.0•10^4
2.5•10^4
Counts


RAQMS N2O July 2014
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude


MLS N2O July 2014
Pressure (mb)
0.1
1.0
10.0
100.0
−50
0
50
Latitude
0
100
200
300
400
(ppbv)


RAQMS vs MLS N2O July, 2014
r= 0.902560
bias= 28.2886 (ppbv)
rms= 59.3632 (ppbv)
RAQMS N2O (ppbv)
0.01
0.10
1.00
10.00
100.00
MLS N2O (ppbv)
0
1•10^4
2•10^4
3•10^4
4•10^4
Counts